MANITOBA RESEARCH COUNCIL

Where science gets down to business.

CA1
DTC800-
90
F273
v.1

41.D

MANITOBA RESEARCH COUNCIL

Prepared for:
Transportation Development Centre
Policy and Coordination Group
Transport Canada

CA1
DTC800-
90
F273
v.1
452299
M
41.D

FEASIBILITY STUDY OF APPLYING MULTIPLEXING TECHNOLOGY TO INTERCITY COACHES
VOLUME I

TP 10522E October 1990

[illegible]
[illegible]
[illegible] U LE
DEC 21 199
Transport Can[illegible] / [illegible] Canada

452299

TP 10522E

91-02511/

FEASIBILITY STUDY OF APPLYING MULTIPLEXING TECHNOLOGY TO INTERCITY COACHES
VOLUME I

Prepared for

Transportation Development Centre
Policy and Coordination Group
Transport Canada

by

Jim Petersen and Ed Paryzek
Engineering Services
Manitoba Research Council

October 1990

The contents of this report reflect the views of the Manitoba Research Council and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

Un sommaire en français de ce rapport est inclus avant la table des matières.

Transport Canada Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.
TP 10522E

2. Project No.
7213

3. Recipient's Catalogue No.

4. Title and Subtitle
Feasibility study of Applying Multiplexing Technology to Intercity Coaches-Volume I

5. Publication Date
October 1990

6. Performing Organization Document No.
441088

7. Author(s)
Jim Petersen and Ed Paryzek

8. Transport Canada File No.
D1465-550

9. Performing Organization Name and Address
Manitoba Research Council
1329 Niakwa Road East
Winnipeg, Manitoba
R2J 3T4

10. DSS File No.
165D.T8200-8-8552

11. DSS or Transport Canada Contract No.
T8200-8-8552/01-SD

12. Sponsoring Agency Name and Address
Transportation Development Centre
200 René-Lévesque Blvd. West
uite 601, West Tower
Montreal, Quebec
H2Z 1X4

and

Motor Coach Industries
Engineering Centre
1558 Willson Place
Winnipeg, Manitoba
R3T 0Y4

13. Type of Publication and Period Covered
Final July/90 to Oct/90

14. Project Officer
Lewis Sabounghi

15. Supplementary Notes (Funding programs, titles of related publications, etc.)
Companion Document, "Feasibility Study of Applying Multiplexing Technology to Intercity Coaches Volume II"

16. Abstract
The use of multiplexing technology in the automotive and trucking industries is currently experiencing rapid growth. The technology provides cost advantages by reducing wiring complexity and improving the maintainability of the vehicles through the use of a serial data bus running throughout the vehicle. The technical and economic feasibility of applying the technology to intercity coaches is investigated using a Motor Coach Industries 102C3 coach as the target vehicle. The main objectives are to evaluate the economic benefits and to define an implementation plan for the orderly incorporation of the technology over the next five years. An assessment of the current practices in the industry is made and issues relating to design integrity are discussed. The report serves as a reference for the use of the technology on MCI coaches, providing detailed cost/benefit analyses.

17. Key Words
Multiplexing, automotive, intercity coach, bus, feasibility study

18. Distribution Statement
Limited number of copies available from Transportation Development Centre on request

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
unclassified	unclassified	-	150	-

TDC/CDT 79-005
Rev 88

Canada

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada
TP 10522E

2. N° de l'étude
7213

3. N° de catalogue du destinataire

4. Titre et sous-titre
Feasibility Study of Applying Multiplexing
Technology to Intercity Coaches - Volume I

5. Date de la publication
octobre 1990

6. N° du document de l'organisme exécutant

7. Auteur(s)
Jim Petersen et Ed Parysek

8. N° de dossier — Transports Canada
D1465-550

9. Nom et adresse de l'organisme exécutant
Manitoba Research Council
1329 Niakwa Road East
Winnipeg (Manitoba)
R2J 3T4

10 N° de dossier — ASC
165D.T8200-8-8552

11. N° de contrat — ASC ou Transports Canada
T8200-8-8552/01-SD

12. Nom et adresse de l'organisme parrain
Centre de développement
des transports (CDT)
200 ouest, boul. René-Lévesque
Tour ouest, suite 601
Montréal (Québec) H2Z 1X4

et

Motor Coach Industries
Engineering Centre
1558 Willson Place
Winnipeg (Manitoba)
R3T 0Y4

13. Genre de publication et période visée
Final juil. 90 à oct. 90

14. Agent de projet
Lewis Sabounghi

15. Remarques additionnelles (Programmes de financement, titres de publications connexes, etc.)
Companion Document, "Feasibility Study of Applying Multiplexing Technology to Intercity Coaches - Volume II"

16. Résumé

Le multiplexage du réseau de câbles dans les automobiles et les camions est une technologie en pleine croissance, du fait qu'elle permet de réduire la complexité de ce réseau et d'accroître la maintenabilité des véhicules grâce à l'utilisation d'un bus série dans lequel transitent toutes les informations nécessaires. La présente recherche vise à étudier la faisabilité technico-économique des applications du multiplexage aux autocars, en l'occurrence l'autocar modèle 102C3 de la Motor Coach Industries. La recherche a eu pour but principal d'évaluer les retombées technico-économiques du multiplexage et de définir un programme d'intégration systématique de cette technologie pour les cinq prochaines années. Le rapport fait un tour d'horizon de l'évolution dans ce domaine et aborde les aspects relatifs à la conformité des systèmes étudiés aux spécifications. Il fournit, enfin, les bases sur laquelle asseoir cette technologie appliquée aux autocars, en faisant l'analyse des avantages-coût de cette technologie.

17. Mots clés
Multiplexage, véhicules automobiles, autocars, étude de faisabilité.

18. Diffusion
Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	--	150	--

CDT/TDC 79-005
Rev 88

Canada

ACKNOWLEDGEMENTS

We wish to thank George Hunt of Transportation Manufacturing Corporation (TMC), and Bryan Couch and Ron Boyecho of Motor Coach Industries (MCI) for providing information on the Motor Coach vehicles. TMC and MCI are sister companies both owned by Greyhound. Appreciation is also expressed to the Society of Automotive Engineers for their permission to print various figures from their papers and specifications.

SUMMARY

1. Introduction

Multiplexing is the transmission of multiple messages over a single channel. It provides the capability of reducing the wiring in a vehicle by using wire more effectively.

To improve vehicle functionality, an increasing level of electronically controlled subsystems are being incorporated. Effective communications with these subsystems are essential for diagnostic and maintenance purposes. In the future communications between the subsystems will be key to improved functionality. Extensive communications between vehicle subsystems become economically feasible through the use of multiplexing technology.

Multiplexing is being actively pursued by the automotive and trucking industries. Up to this point little has been done to consider the use of this technology on intercity coaches.

The purpose of this report is to investigate the technical and economic feasibility of applying multiplexing technology to intercity coaches. MCI has provided assistance in evaluating the technology for use on their 102C3 coach. The main objectives are to evaluate the technological and economic benefits of using the technology and to define an implementation plan for the orderly incorporation of the technology over the next five years. The report is intended to provide a reference on the use of the technology as it applies to coaches. Multiplexing technology is experiencing a rapid growth. As more information becomes available, the report can be updated to incorporate the latest developments.

The scope of the report involves an assessment of current practices in the automotive and trucking industries and the refinement of these practices for use in intercity coaches. This is accomplished by structuring the report into four distinct components; technical assessment, system level design, cost/benefit analysis, and recommendations for future work. The technical assessment serves as the foundation for the entire study by specifying functionality requirements and recommending measures that are necessary to ensure that design integrity is maintained in an actual system. A system level design is then presented which documents a recommended design approach and estimated system cost. This information is then used to perform a cost/benefit analysis which provides the data necessary to determine the scope and overall direction for future work.

2. Current Practice

2.1. Classes of Multiplexing

Three classes of of multiplexing have been defined:

Class A - low speed body wiring and control functions, e.g., control of exterior lamps.
Class B - moderate speed data communications, e.g., sharing of vehicle parametric data.
Class C - high speed real time control, e.g., high speed link for distributed processing.

Class A systems are lowest cost and Class C systems are highest cost. Economical multiplexed systems can be built by using the different classes where necessary.

2.2. Trucking Industry

The trucking industry began defining multiplexing requirements around 1983. Class B systems are currently used in the trucking industry whenever electronically controlled engines (such as Detroit Diesel's DDEC II) are incorporated.

A multiplex-compatible dash is available as an option for these vehicles.

2.3. Automotive Industry

The automotive industry has been active in multiplexing since the late seventies. Several production vehicles have incorporated multiplexing systems: e.g., the Chrysler New Yorker, the Cadillac Allante, and the Buick Riviera.

3. Necessity of Standardization

Both the automotive and trucking industries want multiplexing standards. Multiplexing standards must be adopted to create a viable and economically feasible system in the long term.

Standards provide the following advantages:

- common maintenance & diagnostic interface;
- multiple sources of components
  - less risk;
  - can take advantage of other companies' R&D;
  - more timely availability of new technology;
- economies of scale; i.e., more use out of the same component;
- reduced engineering effort due to well-defined equipment interface.

The Society of Automotive Engineers (SAE) has been active in developing standards for both automobiles and heavy-duty vehicles.

3.1. Potential Standards

Currently there are no "standards" for multiplexing. "Recommended practices" are presently being used. Once a recommended practice has matured enough, it becomes a standard.

SAE J1708/J1587 (recommended practices for heavy-duty vehicles) were originated around 1983 and are popular in the trucking industry. They are close to becoming standards. They are supported by Detroit Diesel's DDEC II engines and will be supported by the Allison Transmission's ATEC II transmissions.

CAN Class C multiplexing (developed by Bosch and Intel) will likely become an international standard as will SAE J1850, an automotive Class B recommended practice.

Class A standards are still in their infancy and are being pursued primarily by the automotive industry. SAE is working on recommended practices for them.

4. Design Integrity

4.1. Noise Immunity

Any electronic components installed on a coach must have adequate noise immunity and transient protection to operate effectively in the coach environment. For the multiplex system, the multiplexed bus, as well as the local node electronics, require protection.

Severe transients exist in the coach's electrical system which must be protected against. Automotive transients are less severe than those of heavy-duty vehicles and this fact may preclude the use of automotive multiplexing components on heavy-duty vehicles (even if the power supply voltages were the same).

4.2. Reliability

The reliability of a coach with a properly designed multiplexed system can be better than that of the current coach. The reliability of an entire electronic module is comparable to the reliability of a mechanical relay.

Electronic reliability depends heavily on packaging and component selection, and VLSI technology will be the key to ensuring high reliability as electronic complexity increases.

Vehicle reliability can be further improved through increased awareness of the performance of various subsystems, so that minor faults can be detected and corrected before they become major problems.

4.3. Fault Tolerance

Fault tolerance is the ability of a system to remain functional in the presence of one or more failures. Faults are inevitable since components eventually fail and undetected communication errors can exist.

Fault tolerance can be designed into the multiplexed system and used as a marketing tool. Wires can be cut or circuit breakers can be tripped to demonstrate the ability of the system to remain functional and diagnose failures.

The multiplicity of nodes in the multiplexing system can be used to advantage in achieving redundancy and fault isolation. The distributed processing allows the system to be less sensitive to the failure of a single processor. For example, if the node displaying the speed on the dash fails, speed can be displayed in digital format on an existing Tell/Tale display until the fault is corrected.

Fault tolerance will become more critical when brake-by-wire and steer-by-wire are supported by the multiplexed system.

4.4. Transparent Expansion/Reduction

Transparent expansion/reduction is the ability to expand or reduce the multiplexed system without affecting its operation.

Transparent expansion/reduction is important for the following reasons:

- a large number of options and specials are used on a coach, and equipment varies from coach to coach;
- it is desirable to take advantage of new equipment as it becomes available, with minimum design effort; and
- it is desirable to support field upgrades by personnel with little or no knowledge of the multiplexing system.

A well-implemented transparent expansion/reduction scheme can improve fault tolerance; i.e., removal of a node is analogous to a node failure. If a data parameter is not available from one sensor, then another source for the same data can be sought for automatically by the system.

4.5. Maintenance Requirements

A well organized plan is required to ensure that the maintenance personnel can cope with an increased level of electronics on the vehicle. This will eventually lead to standardized diagnostic equipment with increasing levels of "intelligence" and automation, which will reduce the level of expertise required by maintenance personnel.

The coach industry is already developing a sense for the importance of the proper electronic maintenance support due to the current maintenance requirements imposed by DDEC and ATEC.

5. Future Coach Requirements

The sophistication and electronic complexity of future subsystems will require multiplexing technology to cope with their communication requirements. Examples of future subsystems include:

- ABS/TC (anti-lock braking/traction control);
- electronic compensated power steering;
- variable bleed rate shocks;
- collision avoidance systems;
- ultrasound backup system;
- navigation systems;
- drive by wire;
- active suspension;
- passenger message centre;
- remote diagnostic links;

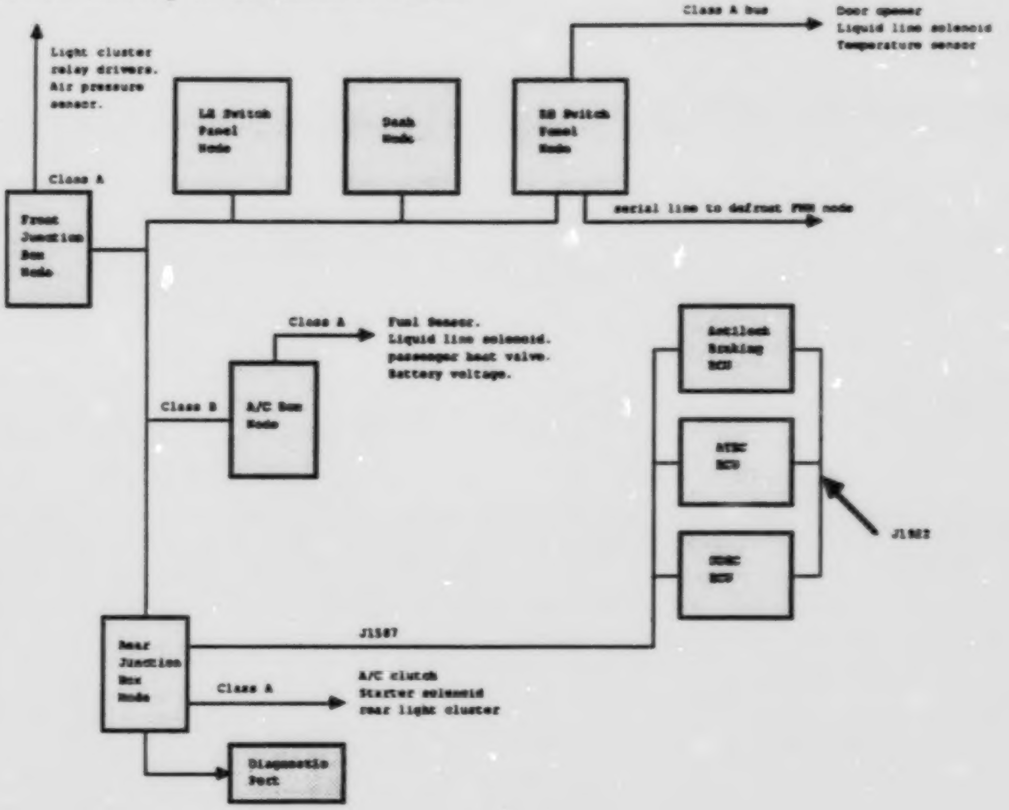
- increased vehicle diagnostics to reduce maintenance; and
- tire temperature and pressure systems.

The multiplexed system will facilitate the incorporation of these features by providing effective communications between these systems (where necessary) and providing a standard interface for maintenance purposes.

6. System Design

6.1. A Potential Multiplex System Design for the MCI 102C3 Coach

A potential system, shown below, consists of a Class B bus (moderate data rate) with several Class B nodes controlling Class A buses (low data rate). No Class C multiplexing is envisioned at this time. Sensors and power switches are connected directly to the Class A buses.



Block Diagram of a Potential Coach Multiplexing System which Eliminates the Main Wiring Harness

Individual devices can be wired directly to a Class A node or have the node built into them. The Class A nodes are then chained together with a pair of wires which connect them to a Class B node which provides the data processing and control.

Hall effect and switch encoders already exist for one Class A system being developed by Chrysler. Packaging design is required since devices are small and not suitable for direct mounting on a coach. They are suitable for mounting inside existing sensors.

In the short term power switches must be interfaced to a quad relay driver and bus interface IC on a circuit board. In the long term power switches will have the interface built in.

6.2. "Generic" Class B Nodes

The hardware functionality of Class B nodes is largely determined by the Class A devices connected to it. The software determines the functionality of the Class B node.

On-board node programming of the device allows the same part to be used interchangeably in different applications. This, however, increases the node cost and affects the manufacturing and maintenance requirements.

The estimated cost for a Class B node is approximately $50 in 100s (which includes a 25% labour charge and a 50% markup). An additional $10-$20 is required for the in-circuit programming capability.

7. Cost/Benefit of Multiplexing

Potentially, substantial savings can be realized by converting existing coach systems to multiplexing.

The elimination of specialized controllers and control relays have the most significant impact on cost savings. These various control functions can be performed by microcontrollers already present in Class B nodes. The savings due to elimination of wire are not as significant. Circuits with multiple loads (such as the aisle lights) will cost more to implement with multiplexing since the wiring is already well utilized in delivering the power.

Isolated conversion of individual subsystems may not provide any economic benefit. Significant savings begin to surface when doing an integrated conversion of several subsystems; in this way the newly converted subsystems benefit from multiplex hardware already present, significantly reducing development and hardware cost.

Aside from the monetary savings, benefits include:

- increased functionality:
  - availability of accessing information already present; e.g., instantaneous fuel rate from the DDEC engine, etc.
  - improving operating efficiency using microprocessor control; a more optimal HVAC (Heating, Ventilation, and Air Conditioning) system could be designed.
  - easy to add new features in software; e.g., control of the driver temperature.
  - can provide some systems for "free"; e.g., a security system could be implemented by necessitating the operator to enter a password on the dash switch-panel;
- reduction in engineering drawings; e.g., a large number of custom harness drawings can be eliminated;
- resource sharing:
  - dash can become the user interface to a host of subsystems; e.g., passenger message centre, destination sign, etc.
  - control algorithms can be distributed among the various processors on the bus - dedicated modules are not required; e.g., HVAC control, intermittent wiper control, door opening, etc.;
- easier incorporation onto the coach of new technology as it becomes available;
- enhanced vehicle reliability;
- ease of tailoring the vehicle to customer requirements both in the plant and in the field; and
- lower maintenance costs due to increased diagnostic capability.

7.1. Offsetting Costs and Risks

The new maintenance skills required can be offset by increased computer assistance (expert systems, or increased automation).

Risk can be reduced through proper planning and implementation. The major areas of risk, as well as some ways to help minimize them, are listed below:

- Low Sales
  - do not artificially inflate costs;
  - provide fault tolerance and maintenance demonstrations;

- Poor Owner Acceptance
  - ensure design integrity and reliability by extensive preproduction testing;
- Poor Maintenance Acceptance
  - ensure thoroughness of diagnostic algorithms and equipment;
  - ensure low Mean Time To Failure;
  - use service personnel feedback during design phase.
- Poor Driver Acceptance
  - use driver feedback during design phase;
  - provide intuitive driver interface which makes the driver feel important.

8. Conclusions and Recommendations

In-vehicle multiplexing technology can be designed to be generic; the same devices developed for the coach industry can be used with little or no modification in other vehicles such as trucks or military vehicles.

Multiplexing offers economic benefits for the present, and even more benefits for the future. Multiplexing will be the key to increased vehicle functionality in the future. The incorporation of multiplexing technology into intercity coaches will become essential to cope with the required data communications and diagnostic/maintenance requirements of future electronic subsystems.

Increased vehicle sophistication is possible with increased reliability.

Multiplexing can be phased into the coaches gradually:

1) convert the tell/tale system and simplify the ATEC/DDEC interface;
2) add Class A lighting control for the front and rear exterior light clusters;
3) convert existing dash gauges to Class B operation;
4) convert existing dash switch panels to Class A operation;
5) convert switch panels to touch-sensitive graphic displays;
6) integrate HVAC system into the multiplex system; and
7) improve other electrical and mechanical subsystems using multiplexing.

SOMMAIRE

1. Introduction

Le principe du multiplexage repose sur l'utilisation d'une seule voie par laquelle transitent de multiples messages, procédé qui, par une utilisation plus intelligente du câblage à l'intérieur d'un véhicule, permet d'en réduire la complexité.

Les fonctionnalités des véhicules automobiles sont en voie d'être rehaussées par un usage plus intensif de l'électronique pilotant les liaisons entre les sous-systèmes et assurant les fonctions de diagnostic et de maintenance. A l'avenir, la qualité des liaisons intersystèmes sera le gage de toute évolution dans le sens d'une extension des fonctionnalités, et le multiplexage pourra en permettre la réalisation dans des conditions économiques.

C'est d'ailleurs à quoi s'activent les secteurs du camionnage et des voitures de tourisme, mais pas encore dans celui des autocars.

La présente recherche s'est donc penchée sur la faisabilité technico-économique des applications du multiplexage aux autocars. La société MCI y a collaboré en prêtant, aux fins d'évaluation, un des autocars modèle 102C3 qu'elle fabrique. La recherche a eu pour but principal d'évaluer les retombées technico-économiques du multiplexage et de définir un programme d'intégration systématique de cette technologie pour les cinq prochaines années. Elle veut en outre fournir les bases sur laquelle asseoir cette technologie appliquée aux autocars. Enfin, elle promet d'actualiser les connaissances pour tenir compte de l'évolution rapide dans ce secteur de pointe.

Le rapport issu de la recherche fait un tour d'horizon de l'évolution dans les secteurs du camionnage et des voitures de tourisme, et des perspectives d'avenir dans celui des autocars. Il s'articule autour des quatre axes de recherche suivants: évaluation technologique, démarche d'étude de systèmes, analyse avantages-coût et recommandations concernant la recherche ultérieure. L'évaluation technologique qui a servi de point de départ à toute la recherche, vise à définir les fonctionnalités et à faire des recommandations sur les moyens à prendre pour s'assurer que le système finalement conçu est conforme aux spécifications. L'étape suivante propose une démarche d'étude de systèmes, dûment documentée et accompagnée d'un devis estimatif. Ces deux éléments servent ensuite à établir le rapport avantages-coût de la démarche pour, enfin, orienter les recherches nécessaires et en déterminer la portée.

2. Situation actuelle

2.1 Classes de réseaux multiplexés

Trois classes de multiplexage ont été définies:

Classe A - Elle regroupe les fonctions de commande et de contrôle de composants de carrosserie, l'éclairage extérieur, par exemple, pour lesquelles la rapidité n'est pas un facteur essentiel.

Classe B - Elle assure la transmission et le partage d'informations sur les paramètres de fonctionnement du véhicule.

Classe C - Elle assure des liaisons rapides en temps réel, dans le cas des systèmes de traitement d'informations distribuées.

Du point de vue du coût, celui-ci va croissant de la classe A vers la classe C. On optimise le multiplexage en veillant à n'utiliser que les classes de composants les plus appropriées à l'usage.

2.2 Camionnage

L'industrie du camionnage a commencé à définir ses exigences en matière de multiplexage vers 1983. Les réseaux de classe B (système DDEC II de Detroit Diesel) sont utilisés par l'industrie du camionnage lorsque les moteurs sont commandés électroniquement.

Dans ce cas, un tableau de bord compatible est prévu à titre facultatif.

2.3 Voitures de tourisme

Les constructeurs de voitures de tourisme ont commencé à adopter le multiplexage vers la fin des années 1970. Des modèles de production série tels que les New Yorker construits par Chrysler, les Allante par Cadillac et les Riviera par Buick, ont été équipés de systèmes multiplexés.

3. Nécessité de standardiser

Les constructeurs de camions et de voitures de tourisme souhaitent la standardisation du multiplexage, afin de favoriser la réalisation à long terme d'un système viable techniquement et économiquement.

La standardisation offre les avantages suivants:

- interface de maintenance et de diagnostic commune;
- diversification des sources d'approvisionnement des composants permettant de réduire les risques, tirer profit de la recherche faite ailleurs, tirer profit à temps de toute découverte utile;
- économies d'échelle: un même composant pouvant avoir plus d'un usage;
- économie de recherche du fait de l'existence d'une interface bien définie.

La Society of Automotive Engineers, (SAE), s'est attelée à la tâche de standardiser le multiplexage dans les camions et les voitures de tourisme.

3.1 Perspectives de normalisation

Il n'existe pas encore de normes de multiplexage, seulement des "pratiques recommandées". Celles-ci peuvent devenir une norme, une fois qu'elles auront été suffisamment rodées.

Les "pratiques recommandées" SAE J1708/J1587 régissant les poids lourds, apparues vers 1983, sont toujours en vigueur, et sont sur le point d'être converties en normes. Elles ont été intégrées dans les moteurs de Detroit Diesel commandés par le système DDEC II et le seront bientôt dans les transmissions fabriquées par Allison Transmission et commandées par le système ATEC II.

Le protocole CAN étudié par Bosch et Intel deviendra probablement la norme internationale pour les réseaux multiplexés C, alors que la "pratique recommandée" SAE J1850 pour les automobiles le deviendra pour les réseaux multiplexés B.

Quant aux normes visant les réseaux de classe A, encore à leur début, elles font toujours l'objet de recherche par les constructeurs d'automobiles. La SAE étudie une "pratique recommandée" les concernant.

4. Conformité aux spécifications

4.1 Immunité aux parasites

Les circuits intégrés incorporés aux autocars doivent être bien immunisés contre les parasites et les phénomènes transitoires, afin de pouvoir répondre aux exigences. Dans le cas d'un réseau multiplexé, le bus ainsi que l'électronique de commande doivent également être protégés.

Le système électrique d'un autocar fait naître d'intenses transitoires contre lesquels des protections sont nécessaires. Dans les automobiles, le fait que les transitoires sont relativement moins intenses risque d'empêcher qu'un réseau multiplexé pour automobiles puisse convenir aux autocars, même à tension d'alimentation égale.

4.2 Fiabilité

La fiabilité des autocars équipés d'un réseau multiplexé de bonne qualité pourrait être supérieure à ceux des autocars classiques La fiabilité de tout un module électronique est égale à celle d'un seul relais électromécanique.

Mais cette fiabilité est conditionnée par le niveau d'intégration des fonctions logiques et par le choix des composants. Aussi, la technologie VLSI sera-t-elle le gage d'une fiabilité d'autant plus élevée que l'électronique de commande est plus complexe.

La fiabilité peut également être accrue par l'attention donnée aux performances des sous-systèmes, de manière à pouvoir déceler les petites défaillances assez tôt dans le processus et les corriger à temps.

4.3 Tolérance aux fautes

La tolérance aux fautes est l'aptitude d'un système à fonctionner normalement en dépit des défaillances qui peuvent surgir. Celles-ci sont inévitables dans la mesure où les composants finissent par se détériorer et où des erreurs de transmission peuvent arriver malgré les mécanismes de détection.

Incorporée au réseau multiplexé, cette aptitude peut devenir un atout sur le plan commercial. La preuve de l'aptitude à fonctionner malgré la rupture d'un câble ou le déclenchement inopiné d'un disjoncteur et à fournir un diagnostic approprié serait alors facile à administrer.

Le nombre élevé de noeuds dans un réseau multiplexé favorise la redondance et facilite le diagnostic des défaillances. Quant à la faculté de distribution, elle rend le réseau moins sensible à la défaillance d'un processeur. Si, par exemple, le noeud par lequel transite l'information de vitesse venait à flancher, celle-ci pourrait quand même être affichée numériquement et provisoirement sur un autre afficheur.

La qualité de tolérance aux fautes d'un réseau multiplexé deviendra vitale lorsque le commande électrique des freins et de la direction deviendra réalité.

4.4 Transparence

La transparence est la faculté pour un réseau multiplexé de supporter l'ajout ou la suppression de noeuds sans que le fonctionnement n'en soit perturbé.

Cette faculté est vitale dans le cas des autocars pour les raisons suivantes:

- le nombre d'équipements facultatifs peuvent y être nombreux et ils varient d'un modèle à l'autre;
- possibilité d'interconnexion d'un équipement neuf sans mise en oeuvre coûteuse; et
- possibilité de rééquipement en clientèle par des techniciens peu ou pas au courant des réseaux multiplexés.

Un réseau multiplexé transparent peut, s'il est bien conçu, accroître l'aptitude de tolérance aux fautes, du fait que la suppression d'un noeud s'apparente à une défaillance. Si un capteur ne parvient pas à fournir l'information prévue, alors le réseau se chargera de trouver une autre source pour cette même information, automatiquement.

4.5 Maintenabilité

Pour répondre à l'envahissement de l'électronique dans le domaine des véhicules automobiles, et permettre aux équipes de maintenance d'y faire face, un plan bien étudié est nécessaire. La finalité de ce dernier pourra être l'introduction à plus ou moins brève échéance de matériels pour le diagnostic des défaillances. Ces matériels, à intelligence croissante et à automatismes de plus en plus poussés, pourront prendre la relève, et les connaissances techniques des équipes d'entretien n'auront plus à être aussi poussées.

L'industrie des autocars s'est déjà familiarisée avec la nécessité d'un entretien électronique de qualité depuis qu'elle utilise les moteurs DDEC et les transmissions ATEC.

5. Exigences futures

Les sous-systèmes à commande électronique qui équiperont bientôt les autocars nécessitent de si nombreuses liaisons de communication que le multiplexage du réseau deviendra la seule solution possible. Une liste prospective de ces sous-systèmes pourrait être la suivante :

- freins antiblocage et régulation de la traction;
- direction à assistance électronique;
- amortisseurs à taux de compression variable;
- systèmes anticollision;
- détecteurs d'obstacles à ultrasons en marche arrière;
- aides à la navigation;
- commande électrique de la direction;
- suspension active;
- centre de communications avec les passagers;
- systèmes de télédiagnostic;
- systèmes d'autodiagnostic pour réduire la maintenance;
- surveillance de la température et de la pression des pneus.

Le multiplexage facilitera l'intégration de ces équipements en pilotant l'échange d'information entre eux et en standardisant l'interface de maintenance indispensable.

6. Etude de systèmes

6.1 Réseau multiplexé possible pour l'autocar 102C3 de MCI

La figure 1 montre le schéma d'un réseau multiplexé qui comporte un bus de classe B (débit moyen) auquel sont interconnectés plusieurs noeuds de classe B qui, eux, contrôlent divers bus de classe A (débit faible). Aucun élément de classe C n'est envisagé pour le moment. Les capteurs et les commutateurs électroniques "intelligents" sont connectés directement aux bus de classe A.

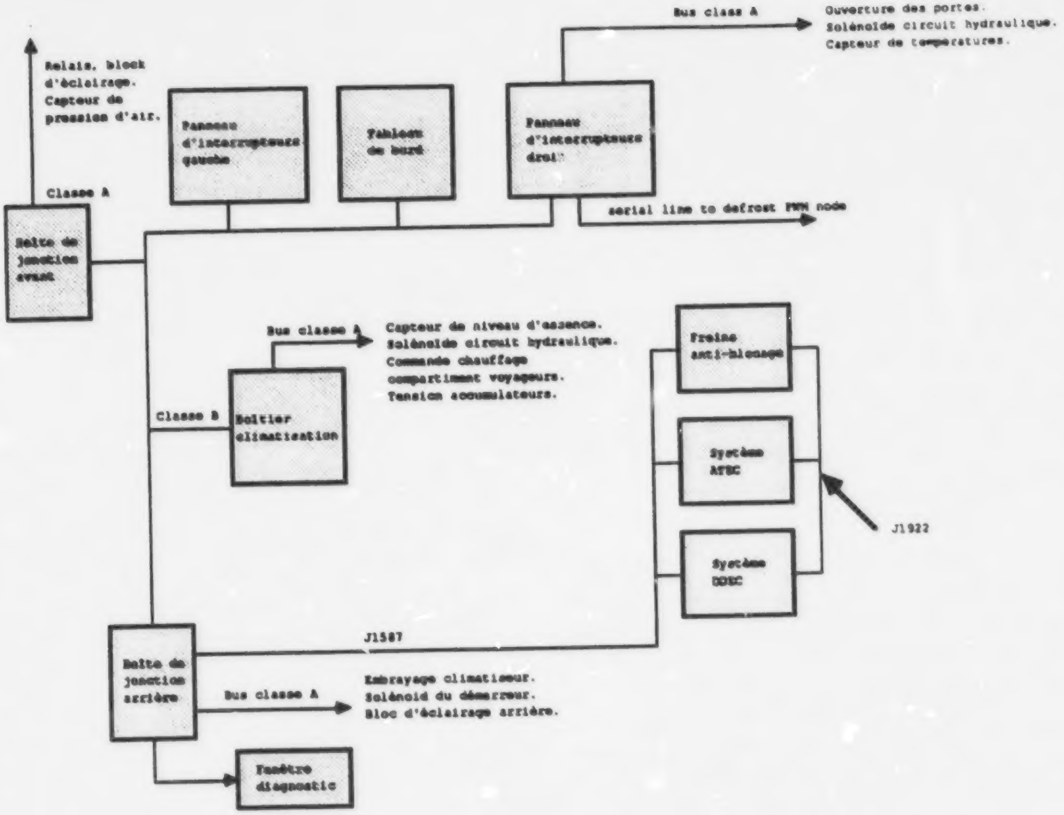


Figure 1 Schéma de principe d'un réseau multiplexé pouvant remplacer l'encombrant faisceau de câbles actuel.

Les divers équipements peuvent être câblés directement à un noeud de classe A ou bien avoir un tel noeud intégré. Les noeuds de classe A sont ensuite interconnectés par des paires de fils à un noeud de classe B qui assure les fonctions de traitement et de contrôle.

Il existe déjà des encodeurs de commutateurs à effet Hall ou ordinaires pour réseau multiplexé de classe A étudié par Chrysler. Cependant, il reste à étudier l'habillage des composants dont la très petite taille n'en permet pas le montage direct. Ils peuvent par contre être intégrés dans les capteurs utilisés.

A court terme, les commutateurs électroniques "intelligents" doivent être interfacés avec un excitateur 4 relais et le bus d'interface sur une carte. Plus tard, cette interface sera intégrée dans les commutateurs.

6.2 Noeuds de classe B

Les fonctionnalités des noeuds de classe B sont conditionnées d'une part par les équipements de classe A auxquels ils sont câblés et, d'autre part, par la qualité des circuits intelligents qui leur sont intégrés.

Il est possible de programmer en clientèle les noeuds de manière à en multiplier les utilisations, mais cela ne fera qu'en augmenter le coût et compliquer les critères de fabrication et de maintenance.

Le coût d'un noeud de classe B est estimé à 50 $ environ les 100, ce qui comprend 25 p. 100 de main-d'oeuvre et 50 p. 100 de marge bénéficiaire. La programmation en clientèle relèvera le coût de 10 à 20 $.

7. Analyse avantages-coût

En principe, le multiplexage dans les autocars existants permettra de réaliser d'importantes économies.

La principale source d'économie viendra de l'élimination des contrôleurs et des relais de commande et de leur remplacement par des microcontrôleurs intégrés aux noeuds de classe B. L'économie des câbles ne sera pas aussi grande. Les circuits à charges multiples (feux éclairant le couloir central) risquent de coûter plus cher s'ils sont multiplexés du fait que les câbles d'alimentation sont déjà optimisés.

Il n'y aura pas grand avantage non plus à multiplexer séparément les divers sous-systèmes. L'avantage viendra plutôt de l'intégration d'un ensemble de sous-systèmes au réseau multiplexé existant, abaissant ainsi les coûts de mise au point et celui du matériel électronique nécessaire.

Outre les économies monétaires, les avantages suivants sont envisageables:

- extension des fonctionnalités:
    - possibilité d'accéder à des informations existantes : lecture instantanée de la consommation d'un moteur DDEC, etc;
    - relèvement du rendement énergétique grâce aux microcontrôleurs; possibilité d'optimisation du système chauffage, ventilation, climatisation;
    - possibilité d'ajouter de nouvelles fonctions: contrôle de la température dans le poste de conduite;

  - possibilité d'assurer "sans frais" certains contrôles : instaûration d'un système de sécurité par l'utilisation d'un mot de passe.
- réduction du temps de conception du câblage du fait qu'on se dispense de nombreux harnais de câbles;
- partage des informations:
  - le tableau de bord peut devenir l'interface entre le conducteur et un grand nombre de sous-systèmes : centre de communications avec les passagers, affichage de destination, etc.;
  - distribution des algorithmes de commande entre les processeurs connectés au bus, éliminant les modules dédiés : commande du système chauffage, ventilation, climatisation; essuie-glace à balayage intermittent; ouverture des portes, etc.
- facilité d'adaptation aux nouvelles technologies au fur et à mesure de leur émergence;
- relèvement de la fiabilité;
- adaptation aisée du véhicule aux exigences du client, en usine ou plus tard; et
- baisse du coût de maintenance grâce à l'aptitude à l'autodiagnostic.

7.1 Réduction des coûts et des risques

Malgré le savoir-faire technique accru exigé du personnel de maintenance, la tâche de celui-ci pourra être allégée grâce à l'électronique: systèmes experts, automatisation plus poussée.

Les risques peuvent être réduits grâce à une bonne planification complétée d'une bonne organisation. Les secteurs de risque, ainsi que les moyens permettant de les atténuer, sont indiqués ci-dessous:

- Mévente:
  - ne pas gonfler artificiellement les coûts;
  - faire la démonstration de la tolérance aux fautes et de l'autodiagnostic.
- Résistance de la part des acheteurs:
  - soigner la qualité et la fiabilité par des essais de présérie.
- Résistance de la part des services de maintenance:
  - s'assurer de la rigueur des algorithmes de diagnostic et de la qualité des équipements correspondants;
  - s'assurer d'une moyenne de temps de bon fonctionnement élevée;
  - mettre à profit l'information venant des services de maintenance.

- Résistance de la part des conducteurs:
    - mettre à profit l'information émanant des conducteurs;
    - prévoir une interface interactive donnant aux conducteurs l'impression qu'ils sont maîtres à bord.

8. Conclusions et recommandations

Banalisé, le multiplexage conçu pour les autocars pourrait servir aussi aux camions et aux utilitaires militaires avec peu ou pas de modification.

Les avantages du multiplexage se multiplieront avec le temps, au point d'en faire le gage de toute évolution des véhicules du futur dans le sens d'une extension de leurs fonctionnalités. Sur les autocars, le multiplexage deviendra indispensable du fait de la multiplicité des échanges d'information, notamment avec l'émergence des systèmes de diagnostic et de maintenance électroniques.

Plus les systèmes seront fiables, plus les autocars pourront évoluer.

Une approche pour l'introduction graduelle du multiplexage pourrait être la suivante:

1) multiplexage des dispositifs lumineux d'avertissement et simplification de l'interface avec les systèmes ATEC/DDEC;
2) multiplexage de classe A pour les blocs d'éclairage et de position avant et arrière;
3) multiplexage de classe B des indicateurs du tableau de bord;
4) multiplexage de classe A des panneaux d'interrupteurs;
5) remplacement des panneaux par des dispositifs d'affichage à écran tactile;
6) intégration du système chauffage, ventilation, climatisation au réseau multiplexé;
7) multiplexage d'autres sous-systèmes électriques et mécaniques.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. MULTIPLEXING OVERVIEW 2
2.1. Description of Multiplexing 2
2.2. Potential Advantages 3
2.3. Classes of Multiplexing 4

3. ASSESSMENT OF CURRENT PRACTICES IN THE AUTOMOTIVE AND TRUCKING INDUSTRIES 8
3.1. The Necessity of Standardization of Multiplexed Systems 8
    3.1.1. Economies of Scale 9
    3.1.2. Component Availability 9
    3.1.3. Uniformity in Diagnostic Equipment 9
    3.1.4. Reduced Engineering Effort 9
3.2. Potential Items for Standardization 9
3.3. Identification of Potential Standards 10
3.4. Currently Used Multiplex Systems and Recommended Practices 11
    3.4.1. Class A 11
    3.4.2. Class B 14
    3.4.3. Class C 16
3.5. Comparison of Potential Standard Multiplexing Systems 17
    3.5.1. Architecture 17
    3.5.2. Access Mechanisms 17
    3.5.3. Protocol 18
    3.5.4. Error Detection 18
    3.5.5. Data Encoding 19
    3.5.6. Hardware and Software Requirements 20
3.6. Conclusions 20
    3.6.1. Predictions for the Future of Multiplexing Standards 21

4. DESIGN INTEGRITY 23
4.1. Noise Immunity Requirements 23
    4.1.1. Data Errors 23
    4.1.2. Transient and Noise Sources 24
    4.1.3. Description of Transients 27
    4.1.4. Protection 28
4.2. Reliability Considerations 29
    4.2.1. Semiconductor Reliability 34
    4.2.2. Enhancing Reliability 35
4.3. Fault Tolerance 35

4.3.1. Introduction ... 35
4.3.2. Types of Faults ... 35
4.3.3. Simultaneous Faults ... 36
4.3.4. Fault Detection and Isolation ... 36
4.3.5. Fault Tolerance of Multiplexing Classes ... 36
4.3.6. Potential Multiplex System Faults and Means to Combat Them ... 37
4.3.7. Maintenance Requirements ... 41
4.3.8. Diagnostic Requirements ... 43
4.4 Transparent Expansion/Reduction Requirements ... 46
4.4.1 Hardware ... 47
4.4.2 Software ... 47
4.5 Data Transmission Requirements ... 50
4.5.1 Conductive Cabling ... 50
4.5.2 Fibre Optics ... 51
4.5.3 Wireless Transmission ... 51
4.6 Architectural Considerations ... 52
4.6.1 Distributed and Centralized Architectures ... 52
4.6.2 Architecture Topologies ... 52
4.7 Harness Considerations ... 55
4.7.1 Porcupine Effect ... 55
4.7.2 Node Connections ... 57
4.8 Power System Requirements ... 57
4.8.1 Requirements for Powering the Multiplex System ... 58
4.8.2 Power Wiring Considerations ... 58

5. COACH REQUIREMENTS ... 60
5.1. Driver Control Requirements ... 60
5.2. Driver Feedback Requirements ... 62
5.3. Diagnostic Requirements ... 63
5.4. Power System Requirements ... 65
5.4.1. Power Requirements ... 65
5.4.2. 12 Vdc Power Requirements ... 67
5.4.3. 115 Vac Power Requirements ... 67
5.5. Load Switching Requirements ... 68
5.6. Sensor and Sensor Switch Requirements ... 76

6. SYSTEM DESIGN ... 80
6.1. Example Multiplexed System Design for the MCI 102C3 Coach ... 80
6.1.1. Class B Node Functions ... 82
6.1.2. Class A Node Functions ... 83
6.1.3. Multiplexing Potential for Class A ... 83
6.2. Choice of Systems to Implement with Multiplexing ... 84
6.2.1. Roof and Parcel Racks ... 84

6.2.2. Video and Audio Systems 85
6.2.3. DDEC, ATEC, and Anti-Lock Braking/Traction Control 85
6.3. Dash Design..85
6.3.1. Transparent Expansion/Reduction 85
6.3.2. "Information Overload" 86
6.3.3. Design Details 86
6.3.4. Future Considerations 88
6.4. Node Design..89
6.4.1. Component Availability 89
6.4.2. Class A Node Design..98
6.4.3. Class B Node Design..102
6.4.4. Software Structure 107

7. COST/BENEFIT ANALYSIS 108
7.1. Introduction..108
7.2. Expected Reduction in Manufacturing Costs..109
7.3. Other Costs 109
7.3.1. New Manufacturing Skills 109
7.3.2. New Maintenance Skills..110
7.3.3. New Engineering Skills..111
7.3.4. Risk Exposure 112
7.4. Other Benefits..113
7.4.1. Ease of Implementing Options 113
7.4.2. Reduction in Drawing Control..113
7.4.3. Reduction in Parts Stockage 113
7.4.4. Increased Functionality in Present and Future..114
7.4.5. Miscellaneous Ideas to Provide Increased Functionality and Reduced Cost..114
7.4.6. Ease of Implementing Field Upgrades 115
7.4.7. Space Savings..115
7.4.8. Reduced Maintenance Costs..115
7.4.9. Increased Vehicle Safety..116

8. DIRECTIONS FOR FUTURE WORK 117
8.1. Technology Constraints..117
8.2. Multiplexing Development for Coaches 117
8.3. Phase I: Determine Strategies and Specifications..119
8.3.1. Determine Realistic Coach Transient Protection Requirements 119
8.3.2. Determine Effects of Arc Welding on Coach Electronics..119
8.3.3. Develop Long-Term Wiring Diagram for Coach Power Distribution 119

8.3.4. Develop Long-Term Wiring Diagram for Coach Multiplex System ... 120
8.3.5. Develop Packaging and Mounting Techniques for the Multiplex Components ... 120
8.3.6. Develop Wiring Techniques for Multiplex Components ... 120
8.3.7. Evaluate Usefulness of Generic Nodes ... 120
8.3.8. Develop Maintenance Strategies ... 121
8.3.9. Develop Long Term Fault Tolerance Strategies ... 121
8.3.10. Develop Hardware Reliability Plans ... 121
8.3.11. Develop Software Reliability Plans ... 122
8.3.12. Summarize Specifications and Generate Report ... 122
8.4. Phase II: Develop Class B System for the Coach ... 122
8.4.1. Develop Tell/Tale Driver Interface ... 122
8.4.2. Develop Simulator for SAE J1807/J1587 ... 123
8.4.3. Develop Tell/Tale Electronics ... 123
8.4.4. Develop Generic Class B Node ... 123
8.4.5. Develop Dash ... 123
8.4.6. Develop Diagnostic Tester ... 123
8.4.7. Beta Test of Class B System ... 124
8.4.8. Cost Analysis and Report on Class B Implementation ... 124
8.4.9. Optimize Class B Multiplex System Design ... 124
8.5. Phase III: Class A Development ... 124
8.5.1. Select Class A Network and Generate Class A Node Specifications ... 124
8.5.2. Investigate Use of ASIC Design for Class A Power Switches ... 125
8.5.3. Develop Class A Quad Power Switch ... 125
8.5.4. Develop Class A Single Power Switch ... 125
8.5.5. Develop Class A Pulse Width Modulator (PWM) Node ... 125
8.5.6. Review Smart Motor Developments ... 126
8.5.7. Convert Class B Node Design to Handle Class A ... 126
8.5.8. Convert Signal Lighting to Class A ... 126
8.5.9. Develop Class A Sensor Switch ... 126
8.5.10. Source Smart Transducers with Built-in Multiplexing Interface ... 126
8.5.11. Convert Engine Starting System to Class A ... 126
8.5.12. Design Class A Fluorescent Ballasts ... 127
8.5.13. Develop Class A Driver Interface ... 127
8.5.14. Convert HVAC System to Multiplex Operation ... 127
8.5.15. Upgrade LCD Dash Display to Incorporate all Gauges ... 127
8.5.16. Upgrade Diagnostic Tester to Handle Class A System ... 127
8.5.17. Convert Coach to Class A Operation ... 128

8.5.18. Beta Test of Class A Multiplexing System 128
8.5.19. Cost Analysis and Report on Class A Implementation 128
8.5.20. Optimize Class A Design 128
8.6. Phase IV: Class C Development 128
8.6.1. Monitor On-going Developments in Class C Multiplexing 128
8.6.2. Upgrade Diagnostic Tester to Handle J1922 Data 129
8.7. Phase V: Develop Specialty Multiplexing Subsystems 129
8.7.1. Evaluate Most Suitable Subsystems for Conversion to Multiplexing 129
8.7.2. Develop Subsystems 129

9. CONCLUSIONS 130

10. RECOMMENDATIONS 132

11. REFERENCES 133

12. BIBLIOGRAPHY 135

LIST OF FIGURES

1 Simplified Schematic of a Multiplexed Coach System....3
2 An Ideal Multiplexing System....5
3 A More Practical Multiplexed System....7
4 CSC Multiplex System....12
5 Sample Application Based on Salplex Series 4000....13
6 J1708 Bus Interface Hardware....15
7 Predictions for the Future of Multiplexing....22
8 Allowable Undetected Error Rates vs. Errors/Year....24
9 Load Dump Waveform Comparison....26
10 Bathtub Reliability Curve....30
11 Allowable Failure Rate per Node vs Number of Nodes....31
12 Short Circuit Protection & Isolation....38
13 Ring Architecture....53
14 Bus Architecture....54
15 Star Architecture....55
16 Porcupine Effect....56
17 Using Class A Buses to Eliminate the Porcupine Effect....56
18 Main 24 Vdc Power Distribution and Junction Boxes....66
19 Location of Loads in the Upper Section of the Coach....70
20 Location of Loads in the Centre Section of the Coach....72
21 Location of Loads in the Lower Section of the Coach....75
22 Coach Sensors & Sensor Switches....78
23 Sample Multiplex System....80
24 Multiplex LCD Truck Dash Display Currently in Use....81
25 One Possible LCD Touchscreen Display....82
26 Quad Class A....96
27 Possible Class A Package....97
28 Possible Connection Between Load and Class A Bus....99
29 Integrated Multiplex Interface....100
30 Possible Class A Packaging Scheme Cutaway....102
31 Detail Cutaway of Possible Class A Package....102
32 Block Diagram of a Class B Node....104
33 Stud Block Type Packaging Option....107
34 Recommended Project Timeline Showing Three of the Five Development Phases....118

LIST OF TABLES

1 Comparison of Potential Multiplexing Standards....17
2 Coding and Framing Violation used for Error Detection....19
3 Typical 12 V Vehicle Transient Voltage Characteristics....25
4 Typical 24 V Vehicle Transient Voltage Characteristics....25
5 Generic Reliability Prediction of Some Common Components....32
6 FMI (Failure Mode Identifier) Diagnostics for J1587....44
7 Differential Pressure Diagnostics for J1587....45
8 Current Limit Settings Specified by J1587....48
9 Wire Gauge Information....59
10 Driver Control Requirements....61
11 Data Requirements for Driver Feedback....62
12 Diagnostic Requirements....64
13 Power Requirements for the Upper Section of the Coach....69
14 Power Requirements for the Centre Section of the Coach....71
15 Power Requirements for the Lower Section of the Coach....73
16 Selection Criteria for Power Switch Ratings....76
17 Coach Sensors & Sensor Switches....77
18 Coach Sensor Summary....79
19 Circuits Having Multiple Loads....84
20 Existing Switch Panel Loads....87
21 Representative Microprocessor Specifications....90
22 Representative Memory Specifications....91
23 Representative Transistor Specifications....95
24 Typical Class A Node Cost Breakdown....101
25 Estimated Manufacturing Savings....109
26 New Manufacturing Skills Required....110
27 New Maintenance Skills Required....111
28 New Engineering Skills Required....111
29 Methods to Reduce Typical Areas of Risk in Multiplex Systems....112

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

A - Ampere
A/C - Air Conditioning
A/D - Analog to Digital
ABS - Anti lock Braking System
ATEC - Allison Transmission Electronically Controlled
AWG - American Wire Gauge
CAN - Controller Area Network
CASE - Computer Aided Software Engineering
CB - Citizens Band
CRC - Cyclic Redundancy Code
CSC - Chrysler Sensor and Control Bus
CSMA - Carrier Sense Multiple Access
DDEC - Detroit Diesel Electronically Controlled
DIP - Dual In-line Package
ECU - Electronic Control Unit
EEPROM - Electrically Erasable Programmable Read-Only Memory
EPROM - Erasable Programmable Read-Only Memory
FDDI - Fibre Distributed Data Interface
FIT - one Failure In 1 billion device hours
GF - Ground, Fixed
GM - Ground, Mobile
HUD - Head Up Display
HVAC - Heating Ventilation Air Conditioning
I/O - Input/Output
IC - Integrated Circuit
ID - Identification
LAN - Local Area Netword
LH - Left Hand
MID - Message IDentification
MOSFET - Metal Oxide Semiconductor Field Effect Transistor
MTTF - Mean Time To Failure
MTTR - Mean Time To Repair
NRZ - Non Return to Zero
OEM - Original Equipment Manufacturer
OTPROM - One Time Programmable Read-Only Memory
PAL - Programmable Array Logic
PC - Personal Computer
PCB - Printed Circuit Board
PID - Parameter IDentification
PWM - Pulse Width Modulation
R & D - Research & Development
RAM - Random Access Memory

RF - Radio Frequency
RH - Right Hand
ROM - Read Only Memory
RPM - Revolutions Per Minute
T/T - Tell Tale
TC - Traction Control
V - Volts
Vac - Volts ac (alternating current)
Vdc - Volts dc (direct current)

1. INTRODUCTION

The purpose of this report is to investigate the technical and economic feasibility of applying multiplexing technology to intercity coaches. MCI has provided assistance in evaluating the technology for use on their 102C3 coach. The main objectives are to evaluate the economic benefits of using the technology and to define an implementation plan for the orderly incorporation of the technology over the next five years. The report is intended to provide a reference on the use of the technology as it applies to MCI coaches. Multiplexing technology is experiencing rapid growth. As more information becomes available, the report can be updated to incorporate the latest developments.

The scope of the report involves an assessment of current practices in the automotive and trucking industries and the refinement of these practices for use in intercity coaches. This is accomplished by structuring the report into four distinct components; technical assessment, system level design, cost/benefit analysis, and recommendations for future work. The technical assessment serves as the foundation for the entire study by specifying functionality requirements and recommending measures that are necessary to ensure that design integrity is maintained in an actual system. A system level design is then presented which documents a recommended design approach and estimated system cost. This information is then used to perform a cost/benefit analysis which provides the data necessary to determine the scope and overall direction for future work.

A detailed cost/benefit analysis for the MCI 102C3 coach is provided in Volume II of the report. Volume II contains confidential information and is not available to the public.

2. MULTIPLEXING OVERVIEW

Throughout this report it is important to distinguish between the terms "bus" and "coach". "Bus" refers exclusively to the electronic data bus used for the multiplexed system. The only exception to this is when reference is made to the truck and bus industry. In this case "bus" refers to the vehicle. In all contexts, "coach" always refers to the vehicle.

2.1. Description of Multiplexing

In general terms, multiplexing is the transmission of multiple messages over a single channel (data bus).

Multiplexing can be done in two ways:

- **Time-Division Multiplexing** - as defined by the ANSI/IEEE Std 100-1988, "permits the transmission of two or more signals over a common path by using different time intervals for the transmission of the intelligence of each message signal."
- **Frequency-Division Multiplexing** - as defined by the ANSI/IEEE Std 100-1988, "permits the transmission of two or more signals over a common path by using different frequency bands for the transmission of the intelligence of each message signal."

Time division multiplexing is used exclusively by both the automotive and trucking industries due to its simplicity of implementation.

In a multiplexed system, the individual systems and devices (referred to as "nodes") transfer data, control, and status information amongst themselves. A large number of these nodes can be connected to the data bus, and node resources can be made available to all other nodes on the bus.

Multiplexing technology is gaining use in the automotive and trucking industries. As vehicle sophistication increases, multiplexing is utilized to relieve congested wiring problems and provides an avenue for gathering diagnostic information from the various electronic subsystems.

Figure 1 is a simplified schematic of a fictional multiplexed coach system, showing a few representative devices on a multiplexed bus.

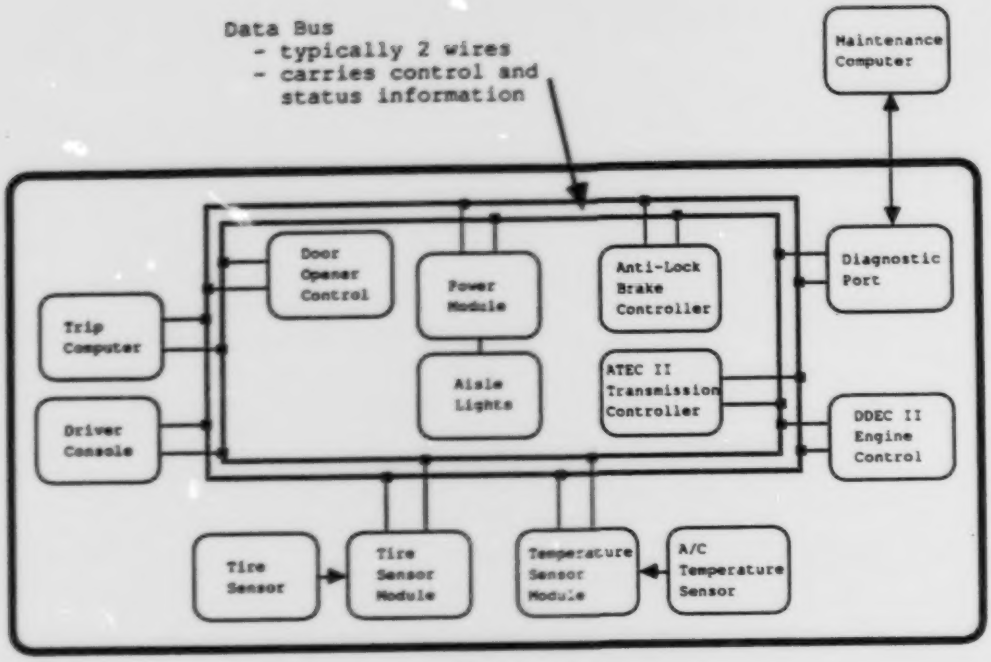


Figure 1 **Simplified Schematic of a Multiplexed Coach System.** The engine and transmission can communicate to optimize shift patterns. Sensor data from the engine controller can be routed to the dash for display. Diagnostic information from all modules can be accessed through the diagnostic port (a simple connector) to facilitate repair.

2.2. Potential Advantages

Potentially, there are numerous advantages to a multiplexed system. These benefits are substantiated in the following sections of the report and in particular, the cost/benefit section.

Potential Advantages

- reduced manufacturing costs
    - simplified wiring
    - resource sharing
    - reduced number of different parts
    - reduced stocking costs
    - reduced cost of implementing options
- reduced documentation costs
- reduced maintenance costs
    - improved vehicle awareness
    - improved vehicle diagnostics
    - reduced troubleshooting time
    - standard repair tools
    - standard repair parts
- improved vehicle performance
- improved vehicle reliability
- increased vehicle safety

2.3. Classes of Multiplexing

An ideal multiplexing system is shown in Figure 2. This system provides the simplest topology but is very expensive. The timing requirements of a few time sensitive devices force all devices connected on the network to communicate at high speed and handle a sophisticated protocol. Not only does each device require a sophisticated interface, but the cost of the bus itself has to be high in order to handle the high data rates and node-loading. With the current level of technology, this system is not cost-effective.

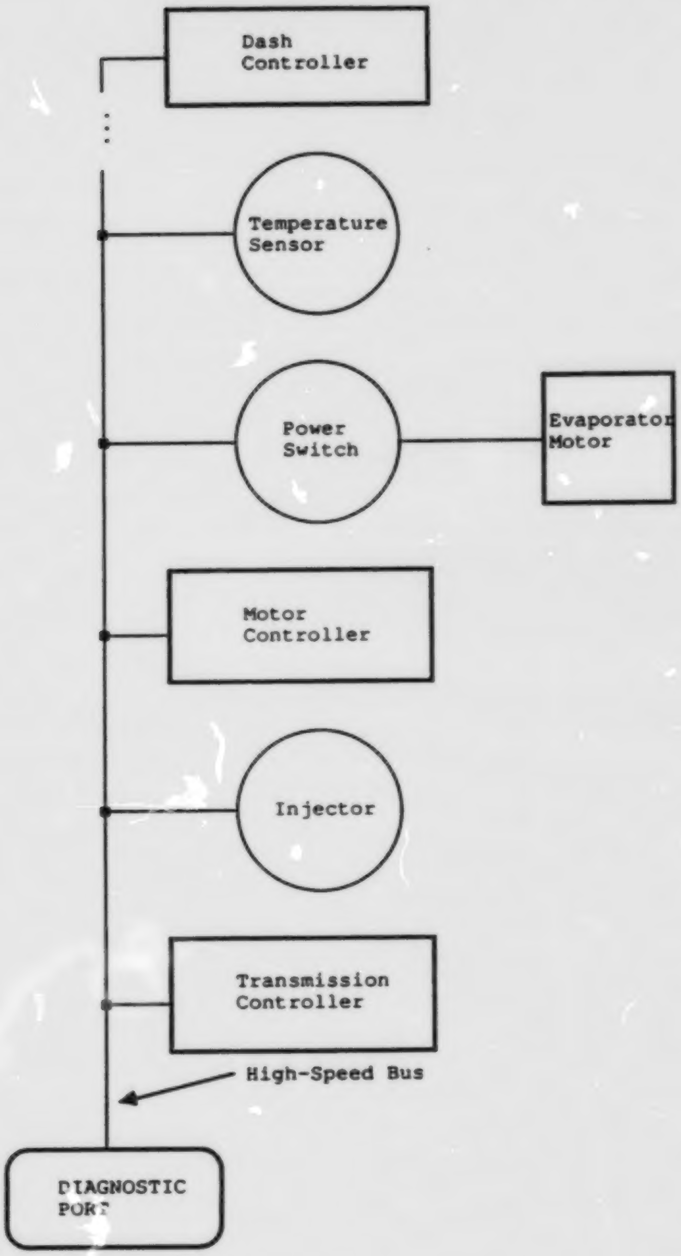


Figure 2 An Ideal Multiplexing System. All devices communicate with the same protocol on a common high speed bus. This system is expensive and requires all nodes to communicate at a high data rate whether they require it or not.

The SAE has defined 3 classes of vehicle data communication networks [1] which can be broken down as follows:

Multiplexing Classes

- **Class A** - low speed body wiring and control functions, e.g., control of exterior lamps;
- **Class B** - data communications, e.g., sharing of vehicle parametric data;
- **Class C** - high speed real time control, e.g., high speed link for distributed processing.

These classes provide a more cost effective solution for multiplexing systems and are driven by the device communication requirements and the costs of satisfying these requirements. The SAE paper also states that "the Class B network is a superset of the Class A bus and the Class C network is a superset of both the Class B and Class A bus (i.e., the Class B bus must be capable of performing the functions of a Class A network, and a Class C bus must be capable of performing the functions of a Class A and a Class B network)."

Figure 3 is a more practical multiplexing example with the various classes illustrated. Due to the different requirements of the three multiplexing classes, it is more practical (cost-effective) to take advantage of these distinctions. Class A devices, which do not require a microprocessor and use the microprocessor in a Class B node to control and receive signals from all devices on the bus, typically operate at speeds less than 1 kilobaud. Class B and Class C devices have microprocessors built in. Class B devices operate at moderate speeds (typically 9.6 - 40 kilobaud) while Class C devices operate at high speeds (typically around 1 megabaud). Some Class B networks can be supported by the microprocessor's serial port whereas Class C networks require custom interface hardware.

Class C provides benefits when distributed processing is required. For example, in active suspension an ultrasound road profile sensor could be used which requires a microprocessor to process the data. The processed data can then be passed along the Class C bus to a microprocessor sensing the force between the wheel and the body and controlling the valves for a hydraulic cylinder.

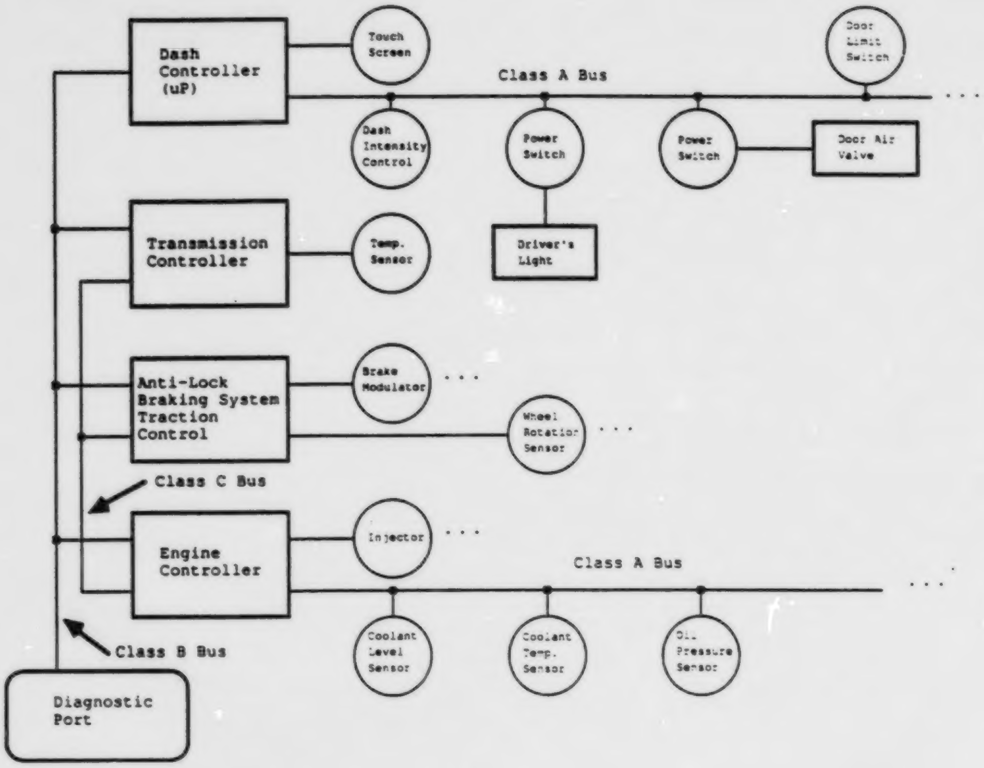


Figure 3 **A More Practical Multiplexed System** showing the distinction between the three classes. Class A nodes communicate at low speed, are low cost and do not require a microprocessor at each node. Class B nodes communicate at moderate speed and use a microprocessor already present to perform the node function. Class C nodes serve time critical functions, communicate at high speed and require a microprocessor.

3. ASSESSMENT OF CURRENT PRACTICES IN THE AUTOMOTIVE AND TRUCKING INDUSTRIES

3.1. The Necessity of Standardization of Multiplexed Systems

Multiplexing has the potential to do for the automotive industry what the open architecture IBM PC has done for the personal computer market. The PC's well-defined open architecture has resulted in the development of a tremendous amount of third party equipment. The result is that inexpensive off-the-shelf circuit boards which can perform a myriad of different tasks are readily available. Furthermore, the computer can be repaired just about anywhere.

Adopting a multiplexing standard offers similar advantages. In fact, it will be the only alternative to create a viable and economically feasible system in the long run. It would just be too risky and costly to have a system which is not compatible with components and maintenance equipment used by everybody else.

It is important, however, to adopt a popular standard with good support and long-life expectancy. For this to occur it is necessary to be very aware of the latest industry trends. On the assumption that a popular standard is adopted, the following benefits will be realized:

Typical Benefits of a Widely Used Standard

- many manufacturers and developers in the market
    - third part support
    - low risk
- new technology research and development
    - application specific semiconductors
    - smart sensors, motors, and switches
    - specialized connectors
- complete subsystems development
    - engine controllers
    - data loggers
    - trip computers
    - customized node controllers

3.1.1. Economies of Scale

Currently, the North American coach market is roughly 1500-2000 units/year, with MCI/TMC supplying approximately 1200 of these units. The coach market by itself does not have the volumes necessary for driving the technology, but by adhering to an established standard it is possible to purchase OEM equipment thus taking advantage of other companies' R&D as well as the reduced component costs arising from high-volume production.

If an *automotive* standard is adopted, it will be possible to take advantage of the greater economies of scale provided by the automotive industry as well as the large existing component and manufacturer base.

The main difficulty with inter-city coaches is that the subsystems required for them, such as anti-lock braking and active suspension, have more in common with the trucking industry components than with those of the automotive industry.

3.1.2. Component Availability

The risk in obtaining components will be reduced since there will likely be multiple sources for the same component. Further, there is the added benefit of more timely availability of new technology and components coming from the R & D efforts of other companies.

3.1.3. Uniformity in Diagnostic Equipment

Standard diagnostic equipment will be readily available from various sources, thus simplifying maintenance. As well, the coach will be able to receive servicing, or at least diagnosis, at any garage or depot around the world which conforms with the same multiplexing standard.

3.1.4. Reduced Engineering Effort

A well defined interface between equipment from different manufacturers will exist. This will greatly simplify the task of taking these various components and designing a system around them.

3.2. Potential Items for Standardization

In a recent SAE paper "In-Vehicle Communication - Standardization and Realization" [2] eight items have been proposed for possible standardization.

Possible Standardization Candidates

- bit-rate;
- bit coding - e.g. PWM, NRZ;
- bus states - physical states of the bus; e.g. voltage levels;
- message attributes - e.g. frame format, arbitration, error handling;
- address/identifier allocation - assignment of specific codes or numbers to units and/or functions;
- data representation - syntax of data;
- transfer medium - e.g. twisted pair, fibre optics, coaxial cable;
- connector.

It should be noted that even the connector to the modules or diagnostic ports should be standardized. This will eliminate requirements for the design and stocking of adapter connectors and multiplexing hardware from different sources.

3.3. Identification of Potential Standards

Currently, there are no established standards in multiplexing although all the major players in the industry are very anxious about having standards established. The primary standards development agency for the North American automotive industry is the Society of Automotive Engineers (SAE). Prior to issuing a standard, the SAE issues a recommended practice. Recommended practices document practice, procedures, and technology that are intended as guides to standard engineering practice. They provide data that has not yet gained wide acceptance and data which is subject to change. Once a recommended practice has gained wide acceptance, it can be nominated to become a standard.

Currently, the closest document to becoming a standard is J1708. J1587 and J1850 are still in a state of change. Recently CAN has been endorsed as a recommended practice for Class C multiplexing for the trucking and bus industries.

For multiplexing, the SAE differentiates between automobile standards and standards for the truck and bus industries. The J1708 and J1587 are recommended practices for Class B multiplexing for the truck and bus industry. J1850 is the Class B recommended practice for the automotive industry. The Class C recommended practice for the truck and bus industry is J1939 and for the automotive industry it's J2056. J1922 is for real-time control of the powertrain in heavy duty vehicles and fits somewhere between Class B and Class C. There are currently no Class A recommended practices that the authors are aware of for the trucking and bus industries. Work is being done to endorse Class A recommended practices for the automobile industry and the SAE has taken out provisional numbers for them. J2057 is for Class A Multiplexing, J2058 is for CSC Multiplexing for Class A Applications.

3.4. Currently Used Multiplex Systems and Recommended Practices

Potential Multiplexing Systems

- Class A
    - SAE J2057 (automotive - provisional)
    - CSC Multiplexing (SAE J2058)
    - Salplex 4000
    - National Semiconductor LMC1051
- Class B
    - SAE J1708 (truck & bus)
    - SAE J1587 (truck & bus)
    - SAE J1850 (automotive)
    - SAE J1922 (heavy-duty vehicles)
    - ISO 9141
- Class C
    - Bosch CAN (SAE J1939)
    - A Bus

3.4.1. Class A

3.4.1.1. CSC Multiplexing (SAE J2058)

CSC multiplexing is being developed by the Chrysler corporation and a number of components are available to support it. Sprague makes hall effect sensors (UGN3055, ~$1.00) which can also function as a bus interface without the hall effect portion, Cherry Semiconductor makes bus transceiver chips (CS8005, approximately $0.40) and EXAR makes a quad relay driver. A capacitive reluctance transducer for measuring fluid levels is in development. CSC multiplexing is also finding use in home alarm systems.

The system requires only a single wire and return path and operates at 1 kilobaud (see Figure 4). Power is supplied to the nodes using the Bus Supply line. Signalling is performed by modulating the current Additional power has to be supplied for loads which might be controlled by the system.

The system can handle up to 30 different input devices and 30 different output devices. Three distinct voltage regions are used on the signal line instead of the normal binary signalling; transitions between 3 V and 6 V are used for controlling outputs, and transitions between 6 V and 9 V are used for selecting inputs.

Inputs and outputs are selected by counting the number of pulses from the control device in the appropriate voltage region. There is no error detection other than provided by the controlling processor verifying the operation. The data rate is low enough that most transients will not confuse the logic (capacitors can be added to the bus to improve the signal/interference ratio). A block diagram of a typical CSC system is shown in Figure 4.

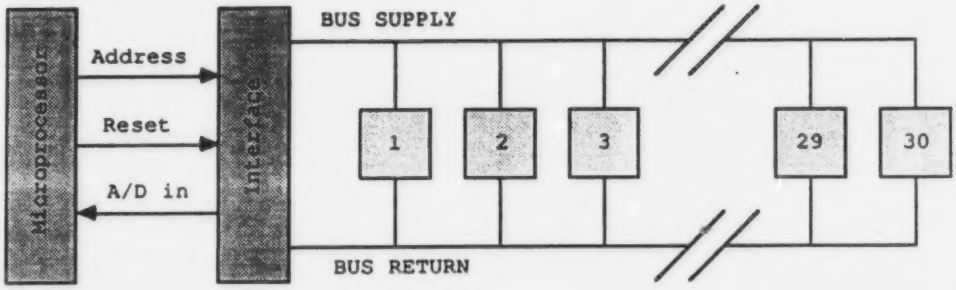


Figure 4 **CSC Multiplex System.** Courtesy of Sprague Semiconductor Group. The vehicle chassis could be used as the bus return path.

3.4.1.2. Salplex Series 4000

The Salplex Series 4000 [3] functions in a star configuration. A single master node services the whole vehicle. Up to thirty-two slaves and associated bus wiring can be connected to the master. Each slave supports 16 channels which can be inputs and/or outputs The total capacity of the system is 512 channels.

The advantage to this system is the simple way in which I/O devices are connected to it. Figure 5 is a sample application using the system. Each data bus is driven by a current source from a 28 V driver and is connected to the common point of a 16-channel analog data selector (the current source can be shorted out by the processor for the control of output devices). A separate 28-V clock line is used to cycle the data selector through all its 16 channels (the clock signal is rectified and powers the data selector). The cycling takes 9 ms; 6 ms to cycle the multiplexer and 3 ms to resynchronize to the start of the cycle. The data bus is connected to an A/D converter and the current source drive from the data bus allows the microprocessor to easily detect switch, closures, and output voltages from resistive type sensors on any of the 16 channels.

N-channel power MOSFET switches (configured as high side switches) can be easily driven by having their gates connected directly to the output of the data selector. The gate capacitance of the MOSFET holds the signal level during the cycling of the multiplexer. Optional shutdown circuitry for the MOSFET shorts out the gate. The gate voltage can be easily read back by the microprocessor to determine if a fault is present. Here, an output line also functions as an input.

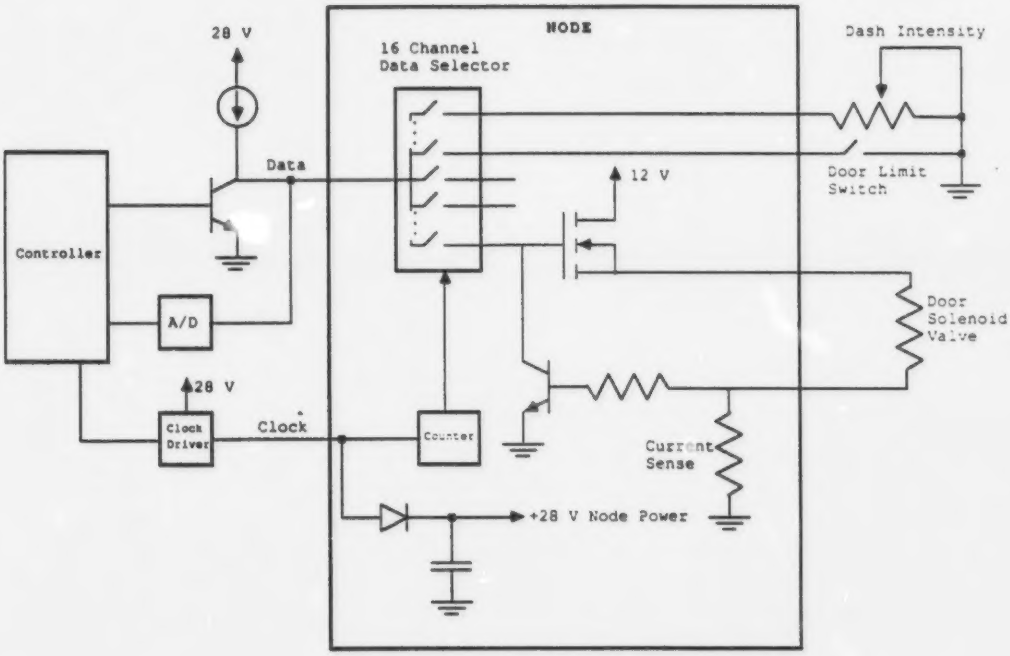


Figure 5 **Sample Application Based on Salplex Series 4000**

The circuitry required for the bus interface at each slave is a 4-bit counter, 16 channel analog data selector, monostable, and a few miscellaneous diodes and passive parts. This costs approximately $1 in quantity. The master contains the voltage boosters and the intelligence required for feedback and control.

The main disadvantages of this system is the amount of wiring required. Each slave requires a clock and data signal from the master which is located at some central point. Connections to power and ground can be provided locally. The wiring from the slave to 16 possible I/O devices can be fairly extensive and special harnesses may be required. Redundant circuitry in the slaves can be wasted since the circuitry requirements at the nodes will vary. The alternative to this is to customize the hardware in each slave which in turn increases the number of different parts required.

3.4.1.3. LMC1051

The LMC1051 is a Class A integrated circuit developed by National Semiconductor [4]. The device is intended for a Class A system consisting of a single master with up to 62 slaves and uses a 2-wire differential bus to communicate between nodes with PWM data. The wiring complexity of the system is higher than that required for the CSC or Salplex systems. Analog signals must be handled on a separate bus. Additional wiring is also required to supply the power.

3.4.2. Class B

3.4.2.1. SAE J1708

SAE J1708 is currently the most widely used recommended practice in the North American trucking industry. It is fairly static and likely to become a standard shortly. It operates at 9600 baud, which is fast enough for all present and anticipated future Class B coach requirements. The protocol is implemented in software and uses the serial port of commercially available 8-bit microcontrollers. The node cost is low. SAE J1708 defines the bit-rate, transfer medium, bus states and some of the address/identifier allocations. No connector is specified.

A detail of J1708 bus interface hardware is provided in Figure 6.

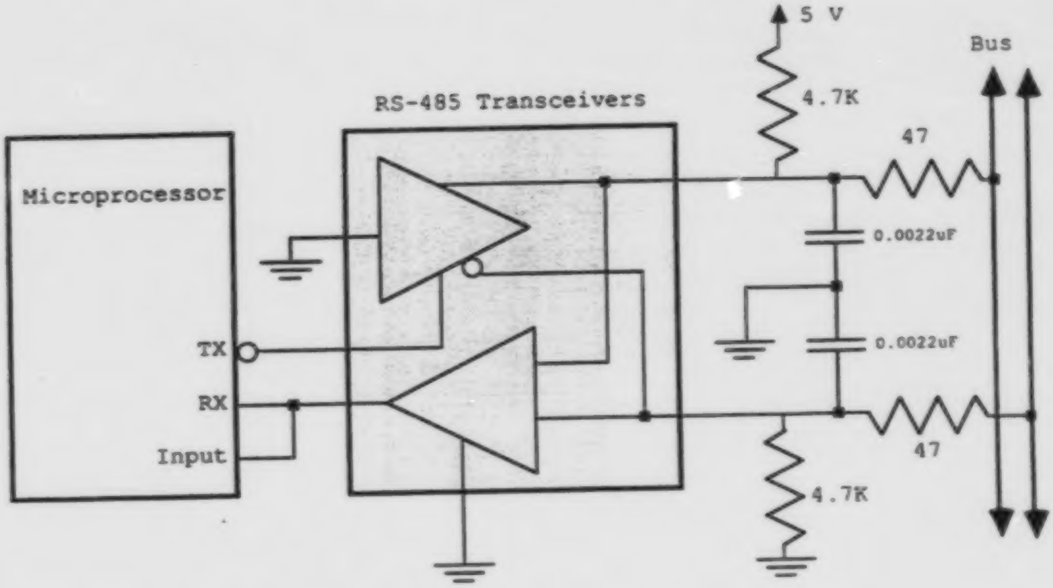


Figure 6 J1708 Bus Interface Hardware (courtesy SAE)

3.4.2.2. SAE J1587

The primary function of SAE J1587 (entitled, "Electronic Data Interchange between Microcomputer Systems in Heavy-Duty Vehicle Applications") is to share data between microcomputers and to provide diagnostic information for maintenance purposes. It defines the data representation, message attributes, and a number of address/identifier allocations not previously defined in J1708. It is concerned with a higher level of communications than SAE J1708.

3.4.2.3. SAE J1922

SAE J1922 (entitled, "Powertrain Control Interface for Electronic Controls used in Medium and Heavy Duty Diesel On-Highway Vehicle Applications") defines the data representation and message attributes needed for real-time control between the engine, transmission, throttle control, and anti-lock braking/traction control subsystem. It is similar in scope to J1587. It is meant to serve as an interim solution until Class C multiplexing is ready to take over. A dedicated J1708 bus is required to support J1922. It is intended that a second J1708 bus be used to support the diagnostic information and sensor data provided by J1587. SAE 1922 will eventually serve to define the higher level communications necessary for CAN similar to the way J1587 does for J1708.

3.4.2.4. SAE J1850

SAE J1850 is an automotive recommended practice which is more difficult to implement than J1708. Both Ford and GM have integrated circuits that support J1850 in hardware. This will likely become the standard in the North American automotive industry for Class B multiplexing. The Japanese and Europeans are also pursuing the use of J1850 [5,6]

J1850 specifies the protocol, access mechanism, and bus states. The message acknowledgement, bit rate, error detection mechanism, and receiver/transmitter characteristics are still subject to variability. This is expected to solidify once standard ICs become popular (hopefully the ICs developed by the North American auto manufacturers all do the same thing. Otherwise the standard may be long in coming).

3.4.2.5. ISO 9141

ISO 9141 is A European standard developed to support diagnostic systems. It is currently used on the Wabco anti-lock braking system, but pressure is being put on Wabco by the trucking industry to convert to J1708/J1587. ISO 9141 specifies the low level communication requirements similar to J1708 (without the address/identifier allocations) and specifies a connector.

3.4.3. Class C

3.4.3.1. Bosch CAN

Bosch CAN is a Class C standard, fully supported and endorsed by ISO for high speed multiplexing. Recently, the SAE Truck and Bus Subcommittee has adopted CAN as the basis for its future recommended practice (J1939) for Class C multiplexing. CAN operates at up to 1 megabit per second, which is likely adequate for most, Class C applications. Intel has an LSI chip available (the 82526) which fully supports the CAN protocol in hardware. Philips Corporation, in Europe, is developing ICs which integrate the CAN protocol, bus transceiver, microcontroller and power switch into one device [2].

The CAN specification addresses the protocol access mechanism, and bus states. The bit rate is left open at 1 megabaud maximum. The transfer medium is not specified though twisted pair is the minimum requirement.

3.4.3.2. A BUS

The A BUS is a European multiplex system used in some automotive applications. Its popularity will fade since CAN has been endorsed as the European Class C standard.

3.5. Comparison of Potential Standard Multiplexing Systems

The potential systems to become standards are J1708, J1850 and CAN. Table 1 shows roughly how they compare. This information is discussed in the following sections.

Table 1 Comparison of Potential Multiplexing Standards

System	Architecture	Access Mechanism	Collisions
J1708	Bus	Priority CSMA/CD	destructive
J1850	Bus	Priority CSMA/CD	non-destructive
CAN	Bus	Priority CSMA/CD	non-destructive

Table 1 (cont.) Comparison of Potential Multiplexing Standards

System	Coding	Protocol	Error Detection	Bit Rate (bit/sec)	Min. 8-Bit Message Time
J1708	NRZ	character	checksum	9600	4.38 ms
J1850	PWM	bit	8-bit CRC *	20.8 k	4.18 ms **
J1850	PWM	bit	8-bit CRC *	41.7 k	2.09 ms **
CAN	NRZ-5	bit	16-bit CRC	1 M	45 - 53 µs

* The 8 bit CRC is not mandatory in the recommended practice.

** This time assumes a message with an 8-bit identifier and no acknowledgements.

*** NRZ with bit stuffing to prevent more than 5 bits being the same value.

3.5.1. Architecture

CAN, J1708, J1850 are based on bus architectures which have no required master node.

3.5.2. Access Mechanisms

CAN and J1850 use a form of Carrier Sense Multiple Access (CSMA) technique with a priority based access mechanism which prevents destructive collisions. The bus uses dominant and recessive states; devices of higher priority have access codes with more dominant states. Each device monitors what it is sending and if it detects a recessive bit being over-ridden by a dominant one, it immediately stops transmitting and allows the higher priority device to continue its transmission. Since destructive collisions do not occur, the bus can be maximally utilized. The high priority devices are thus guaranteed low latency time to transmit their messages.

J1708 has compromised this technique to minimize the hardware requirements and allowed transmitting devices to continue transmitting the current character after a collision is detected. This means that collisions can occur and the bus is not used as efficiently. The dominant and recessive states are used.

3.5.3. Protocol

J1708 uses a character-oriented protocol and each character has a start and a stop bit. Idle time is required at the end of each transmission. Messages are broadcast on the bus and no acknowledgements are provided from the receiving devices.

CAN uses a bit-oriented protocol where normal data coding violations are interpreted as error flags (six constant bits) or end-of-frame markers (greater than seven constant bits). A global acknowledgement is provided by all receivers outputting a recessive state. A dominant state from any receiver indicates an error. Software can be used to determine when a node is faulty so that it doesn't lock the bus [7].

J1850 uses a bit-oriented protocol where data encoding violations are used as delimiters. Acknowledgements can be none, an 8-bit acknowledgement identifier from all nodes (dominant states override recessive ones), or one or more bytes containing specific acknowledgements from each of the intended recipients

3.5.4. Error Detection

Error detection is provided by cyclical redundancy check, checksums, and coding and framing violations.

The error detection field for J1850 is optional at this time but an 8-bit cyclic redundancy check is likely implemented in the Ford and GM J1850 chips. Checksums can be used in the data field if desired.

CAN uses a 15-bit CRC sequence which Bosch claims to have optimized for automotive applications [7]. Bosch claims that the undetected error rate for the CAN protocol is much better than 3.5×10^{-5}. This is superior to any of the other protocols. It should be noted that in order to get the overall undetected error rate of the communications channel, this rate must be multiplied by the error rate of the communications channel (determined by the signal level, noise and interference present in the channel).

J1708 uses a 8-bit checksum which is the inverted two's complement sum of the data and address field.

3.5.5. Data Encoding

Two main types of data encoding are currently used in automotive multiplexed systems: Pulse Width Modulation (PWM) and Non Return to Zero (NRZ). Biphase and Manchester are used in many LAN networks.

PWM uses three clock periods to represent one bit of information. A wide pulse (2 clock intervals) represents data of one polarity, and a narrow pulse (1 clock interval) represents data of the opposite polarity. NRZ uses one clock interval to represent the data by the signal being either high or low. Biphase or Manchester encoding uses two clock intervals for encoding one bit of data. There is always a transition of the signal at the center of the bit and the direction of the transition determines what the bit is.

The type of encoding used directly affects the throughput on the link and its ability to tolerate clocking frequency innaccuracies of other units. NRZ provides the maximum throughput, but suffers from lack of clock synchronization when large bursts of constant level data occurs. CAN uses NRZ with bit-stuffing to prevent data staying in the same state for more than five bit times. The maximum time between data edges is five bits. This provides adequate synchronization and offers higher throughput than PWM or biphase [7].

The data encoding used also affects the noise emitted. NRZ is preferred to PWM or biphase due to the random nature of the data (the energy emitted is distributed over a wider bandwidth and hence has lower amplitude peaks). Biphase and PWM encoding techniques tend to concentrate their emissions at particular harmonics and subharmonics of the clock frequency. The improvement of NRZ over PWM may only be in the order of 2 or 3 dB [1].

The choice of data encoding can also provide improved error detection in the presence of transients. Transients tend to cause the line to go high or low for several bits in a row which will cause coding violations and framing errors. Table 2 describes the worst case time intervals to generate these kind of errors for different multiplexing systems.

Table 2 Coding and Framing Violation used for Error Detection

System Name	Encoding Technique	Error Type	Detection Interval	Detection Time
J1708	NRZ	framing error	8 bits	832 μs
J1850	PWM	coding error	3 bits	150 μs
CAN	NRZ-5	coding error	5 bits	5 μs

Another aspect of the encoding technique is the ability to ac-couple the data. Ac-coupling allows the data receiver to adjust its bias to the optimum threshold. This can help the fault tolerance because shorts or opens on either of the data bus lines will not re-bias the receiver. Biphase data has no dc-component and so it can be easily ac-coupled. PWM data has a dc-component which goes between 1/3 and 2/3 of the signal amplitude. It is is also possible to ac-couple this signal with only slight degradation in performance. A circuit can be used to recover the lost performance [7]. The dc-component for NRZ data can be at either extreme of the signal excursion and so it is not possible to ac-couple the signal. For NRZ, electronic circuitry must be used to detect the presence of shorts or opens. This circuitry can be integrated into the IC handling the communications [2].

3.5.6. Hardware and Software Requirements

J1708 requires only the serial port of a microcontroller, an external RS-485 transceiver, and a few passive components. The software overhead is quite heavy, especially when trying to transmit.

A special chip is required to implement the J1850 protocol since a software implementation would be too difficult. The interface between the processor and the J1850 chip is currently unknown. An interface similar to a UART would still represent a fair load on the processor since characters can be potentially received or transmitted every 192μs at the 41.7kHz data rate.

CAN uses a custom IC to implement the protocol. The processor interface is very simple since in-coming and out-going messages are treated as objects. For in-coming messages, the processor indicates what messages it wants to receive and when a desired message is received it is written into a dual-port RAM and an interrupt is generated. The processor can simply read the contents of the message from the dual-port RAM. Out-going messages are written into the RAM and the chip takes care of the rest.

3.6. Conclusions

The automotive industry is actively working with multiplexing technology. Both Ford and General Motors already have VLSI devices that implement the SAE J1850 protocol in hardware. The GM chip will soon be offered commercially and is expected to sell in the $4 to $6 dollar range. With such integrated circuits available, a J1850 node can be quite cost-effective to implement. The automotive industry deals with orders-of-magnitude greater volumes than both the trucking and coach industries combined, so their support of the J1850 protocol represents potentially greater economies of scale and a greater variety of support components for that standard.

It appears that CAN will likely become a worldwide standard for multiplexing across the whole range of vehicles. The component volumes will therefore bring down the cost of the Class C nodes making the ideal multiplexed system of Figure 2 more of a reality. Philips appears to be attempting to integrate power switches onto the same chip which implements the protocol and control [2]. This will be a major event for multiplexing technology since up to this point most people are considering multiple chip solutions (which are inherently more expensive and less reliable). The following quote from Intel's "Microcomputer Solutions" magazine describes CAN's endorsement:

> *"The Truck and Bus Communications and Control Subcommittee of the Society of Automotive Engineers (SAE) has selected the Controller Area Network (CAN) protocol as the basis for its future recommended practices. Because the SAE is the primary standard-setting organization for the U.S. automotive industry, the Truck and Bus Subcommittee's decision opens the door for acceptance of the CAN protocol by other automotive standard-setting committees.*
>
> *"The increasing implementation of serially linked, electronics-based communication/control systems results in vehicles that are more reliable, safer and easier to manufacture. The SAE Truck and Bus Subcommittee spent more than two years evaluating existing and proposed protocols for truck and bus control and communications networks before endorsing the CAN protocol. Factors that led to the CAN acceptance by the Subcommittee include CAN's high-speed data rate performance, reliability, availability in silicon, cost effectiveness and synergy with the direction of other standards-setting organizations.*
>
> *"Intel has long supported the CAN protocol, which was developed by Robert Bosch GmbH for in-vehicle multiplexing applications. Intel's CAN controller, the 82526, is the first silicon implementation of the CAN protocol; the 82526 will be used in 1991 model year production vehicles."[8]*

3.6.1. Predictions for the Future of Multiplexing Standards

The predictions presented in this section, and graphically depicted in Figure 7, are the authors' own opinions.

CAN will become an international standard for multiplexing in the automotive and trucking industry. In the long term, CAN will likely phase out J1708 systems. Aspects of J1922 and J1587 will be combined to form a higher level communication specification under which CAN will operate. A Class A standard will emerge and operate as branches for a Class C trunk system - largely to reduce the node loading on the high speed Class C bus and reduce cost. In the medium term, diagnostic information and low speed data will continue to be handled by J1708 and J1587. J1708 and J1587 will continue to exist in the long term due to the large installed base.

J1850 will likely become an international standard and may begin to compete with J1708 in the future. It is a good choice for handling moderate speed data and will compete with CAN for real-time control when the high data rates are not required.

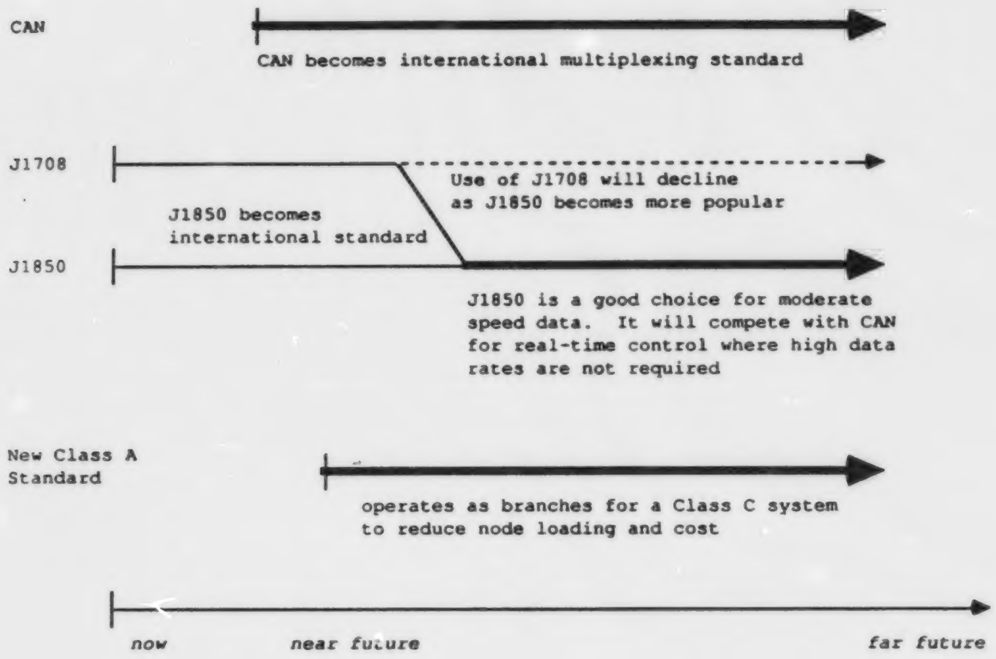

CAN
CAN becomes international multiplexing standard
J1708
Use of J1708 will decline
as J1850 becomes more popular
J1850 becomes
international standard
J1850
J1850 is a good choice for moderate
speed data. It will compete with CAN
for real-time control where high data
rates are not required
New Class A
Standard
operates as branches for a Class C system
to reduce node loading and cost
now
near future
far future

Figure 7 **Predictions for the Future of Multiplexing**

4. DESIGN INTEGRITY

This section outlines the key issues involved in ensuring the design integrity of a viable multiplex design for inter-city coaches.

Noise immunity, reliability, and fault tolerance are some of the key issues discussed. These factors determine, to a large extent, the physical makeup of the multiplex system:

- the type and kind of cabling to use;
- semiconductor protection circuitry and devices; and
- other software and hardware issues.

Other issues which play major roles in the determination of a viable multiplex system include the power system requirements, data transmission requirements, expansion/reduction requirements, and diagnostic and maintenance requirements.

4.1. Noise Immunity Requirements

To maintain reliability, it is crucial that the multiplexed system and its components be relatively immune to the effects of electrical noise and transients that can manifest themselves on the power and signal lines. Transients can damage electrical components. Transients and noise can cause data errors and intermittent operation.

4.1.1. Data Errors

Data errors can often be detected through the use of checksums and error correction algorithms and by checking for coding and framing violations. However, these means are not foolproof and there is a finite (though very small) probability that some errors will be undetected.

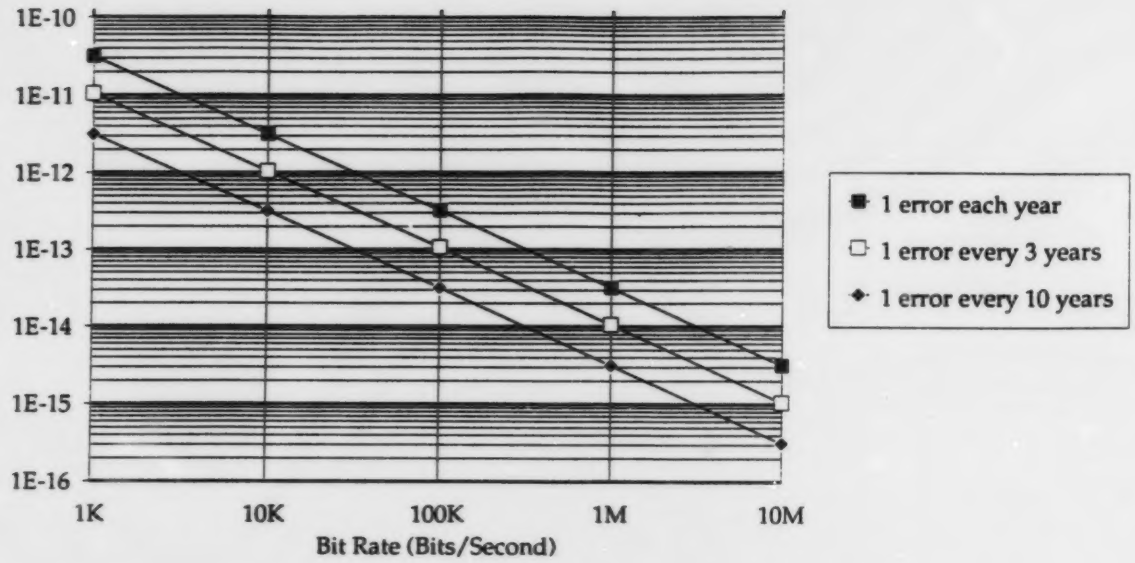


Figure 8 **Allowable Undetected Error Rates vs. Errors/Year.** The chart applies to 24 hour per day operation, 365 days a year. For lessened operation, the average bit rate can be scaled down accordingly.

Figure 8 shows the required overall data error rates required to achieve acceptable performance. One undetected error per year is usually deemed satisfactory. The dependency on bit rate should be noted in Figure 8. As the data rate increases, the error detection algorithms must increase in complexity to provide the same level of performance. A favorable factor is that transients will more easily cause data coding violations as the bit rate increases. These kinds of errors are easily detected.

Even though the overall undetected error rate may be low, an excessive amount of errors can seriously degrade the data throughput. The result is that latency requirements are not met. The degradation in throughput is highly dependent on the protocol and should be considered when the detailed design is made.

4.1.2. Transient and Noise Sources

Transients in vehicles can result from a number of mechanisms including load dumps, inductive switching, mutual coupling, and static discharge. A not so well defined transient for the trucking and bus industry is one resulting from arc welding. Noise can also be coupled into the power supply lines by some accessories and external sources such as radio transmitters. Transients, as defined by SAE J1455, are indicated in Tables 3 and 4. These are of sufficient magnitude to affect the functioning of the components and destroy them.

Table 3 **Typical 12 V Vehicle Transient Voltage Characteristics**
(from SAE J1455 unreleased revision)

Lines	Type	Source Imped. (ohms)	Rise Time (µs)	Open Circuit Characteristics
power	load dump	0.1	100	14 + 106e(-t/0.4)
power	field decay	?	100	-90e(-t/0.0038)
I/0 (note 1)	inductive switching	20	1.0	14 +/- 600e(-t/0.001)
I/0 (all)	mutual	50	1.0	14 +/- 300e(-t/0.000015)

Note 1. This transient affects only I/0 lines which may be connected to unclamped inductive loads.

Table 4 **Typical 24 V Vehicle Transient Voltage Characteristics**
(from SAE J1455 unreleased revision)

Lines	Type	Source Imped. (ohms)	Rise Time (µs)	Open Circuit Characteristics
power	load dump	0.2	100	28 + 212e(-t/0.4)
power	field decay	?	100	-150e(-t/0.0038)
I/0 note 1	inductive switching	20	1.0	28 +/- 600e(-t/0.001)
I/0 all	mutual	50	1.0	28 +/- 300e(-t/0.000015)

Note 1. This transient affects only I/0 lines which may be connected to unclamped inductive loads.

The values in Tables 3 and 4 are closer to worst case numbers and are likely on the high side. It is important that the specifications are realistic because they will affect the cost of the multiplexing nodes. In the case of semiconductor power switches, over-specifying the transient limits will have a major cost impact. Figure 9 is a comparison between the load dump waveforms derived from J1455 and one derived from the Ford Engineering Specification. It is important to note, however, that the Ford specification is dealing with typical *automotive* transients, while the SAE specifications deal primarily with trucks and other heavy-duty vehicles (which will have more severe transients due to their larger batteries, alternators, and inductive loads).

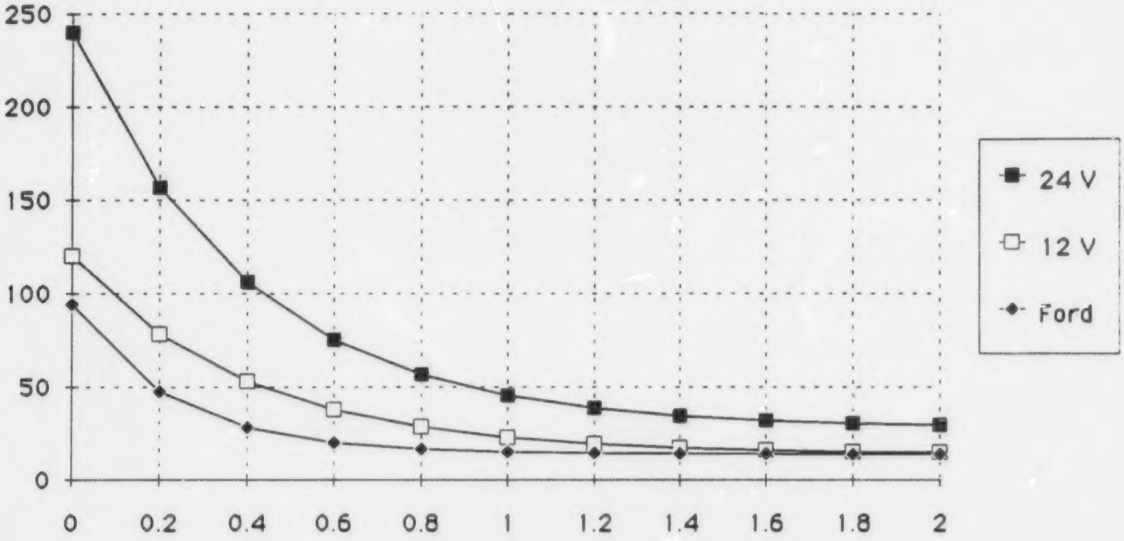


Figure 9 **Load Dump Waveform Comparison.** The horizontal axis is in seconds, while the vertical axis is in volts. The 24 V and 12 V waveforms are from the equations in Tables 3 and 4.

"Normal" transients can be expected to be of a much lower magnitude. Motorola offers an automotive series switch transient protector device, the MC3397, which they claim is capable of withstanding load dumps of up to 40 V. They also manufacture a higher-capacity version capable of withstanding 60 V load dumps. It is interesting to note that the Motorola specifications are much lower than those of Ford and SAE; nonetheless there appears to be a market for the chip. Other semiconductor manufacturers are also claiming load dump protection on many of their automotive products, and these are also of the order of 50 or 60-V protection.

The major problem with some SAE specifications (such as J1113) is that they do not provide adequate information about source impedances and the available energy levels. This information is critical in determining the power and current handling requirements of the transient suppressors. There are also several inconsistencies in the definitions of transients in SAE J1455 and the document requires correction. The SAE has been notified. As well, the Ford specification does not provide details of the source impedances but it does provide diagrams of test fixtures for evaluating the immunity of equipment to these transients. These fixtures typically have 4 ohm source impedances.

4.1.3. Description of Transients

4.1.3.1. Load Dump Transient

The load dump transient is the most severe transient due to its large magnitude, low source impedance, and long duration. A load dump occurs when the alternator load is abruptly reduced. Due to the inductive nature of the alternator, a high voltage spike is generated. The worst transient is caused by a faulty battery terminal connection where high current is being intermittently sourced to a weak battery. During the transient the battery is not in the circuit to act as a capacitor to reduce the voltage. It is too difficult to suppress the energy with transient suppressors and the best technique to combat it is to make the circuit tolerate the peak voltage. For power switches the transistors must be selected with high enough collector-emitter or drain-source breakdown voltages.

4.1.3.2. Inductive Load Switching Transient

The inductive transients are caused by interrupting the current to inductive loads such as solenoids, motor fields, air conditioning clutch, etc. Whenever such an inductive accessory is turned off, a large voltage transient results. To date (SAE J1455, January 1988) no measurements of this transient have been performed with standardized procedures so little data is available. These transients are normally handled by placing reverse-biased diodes across the load.

4.1.3.3. Mutual Coupling

The coupling occurs when there are cables in close proximity and is generally caused by long harnesses, non-shielded conductors, and common ground return impedances. When several wires are bundled in a harness and an abrupt current or voltage change occurs on one of them, the mutual coupling (inductive or capacitive) between them can result in voltage and current spikes the other wires. The energy from these transients can easily be handled by zener diodes or transient suppressors.

4.1.3.4. Accessory Noise

Noise generated through the normal functioning of various accessories is typically limited to about 1.5 V peak within a 50-10000 Hz band width. Though small, this noise can still affect the functioning of other devices. The noise can affect control circuits but it can be effectively filtered using RC filters.

4.1.3.5. External Sources

External sources of radiated energy may also affect the coach electronics and electrical system. Radar installations, radio and microwave transmitters, and power stations are all sources. However, the coach electronics are protected somewhat against outside electromagnetic influences by the exterior metal skin of the coach. External radiation is not likely to play as significant a role as the internally generated transients.

4.1.3.6. Electrostatic Discharge

Charge can build up on various surfaces during normal coach operation and be randomly discharged into electrical devices. As well, a static discharge can be induced into the multiplexed bus by a service technician during maintenance. J1455 recommends that device lines must withstand the discharge of a 300 pf capacitor, charged to 15 kV, through a 5 kilohm resistor. The Ford specification uses a 200 pf capacitor, charged to 15 kV, through a 1.5 kilohm resistor.

4.1.3.7. Arc Welding

Repairs and modifications are sometimes made to the coaches using arc welding. The transients generated may be significant enough to destroy the control modules for DDEC and Detroit Diesel recommends removing the power supply and grounds from the control module before arc welding is performed. The exact mechanism which can destroy the modules is currently unknown and there could be large currents flowing through the ground circuitry or inductively related transients which occur at the start and termination of the arcing. More investigation into this phenomenon is required, but it is likely that large voltages are induced into the loops formed by grounding of components on the chassis and the signal wiring.

4.1.4. Protection

The amount of voltage stress a component is subjected to has a direct effect on its reliability. Voltages must be constrained as close as possible to their normal operating limits. This can be effectively achieved using transient suppressors or using devices which can tolerate the high voltage.

It is relatively straightforward and inexpensive to protect the control electronics, since small current magnitudes are involved in their operation. Thus relatively high source impedances can be used to source the current, and these limit the power dissipated in the transient suppressors when a transient occurs. The fact that low power levels are involved means that it is possible to integrate the transient suppression devices into the same IC for cost effectiveness. AGS claims to have ICs which are internally protected against load dump transients.

Protecting a power switch is a different matter. Here, higher amounts of current are being handled and low source impedances are required. When transients occur, large amounts of power can then be delivered to the transient suppressor. One advantage is that the load impedance limits the transient current. To further lessen the transient suppressor requirements, it is possible to design the the power switch so it dissipates the transient energy itself. Motorola's new "E" series power MOSFETs incorporate this feature. The integral zener diode can not handle the level of energy which would be dissipated from a load dump but it can handle the other transients. To handle the load dump transient, the device must have a drain to source voltage capability greater than the peak voltage expected.

Since the multiplexed coach will have a large number of electronic subsystems onboard, a possible plan of attack may be to address the voltage transient problem globally; that is, provide suppression at the source of the problem. The main drawback with this approach is that if the transient suppressor fails or becomes disconnected, many devices may be destroyed. This approach may be suitable for transients associated with the alternator (these transients have the highest energy), but many of the transient sources, such as mutual coupling and arc welding, are more distributed in nature and a global suppression technique is not feasible.

Signal lines on devices can usually be adequately protected from static discharge and other transients by providing a discharge path to ground or to the power supply. This typically does not pose a major problem due to the large source impedances and small energy levels involved.

Mutual coupling of unwanted noise into devices can be minimized by utilizing adequate shielding and keeping connecting wires and traces short. For longer runs, cost effective shielding can be provided by running the wire close to a metal surface away from other wires. The closer the wire is to the metal surface, the better the inductive shielding becomes. Added protection can be provided using twisted pairs, co-axial cables, or shielded twisted pairs. Fibre optic cables can be used as well, since they are virtually immune to the effects of electromagnetic noise, but are considerably more expensive.

4.2. Reliability Considerations

The failure rates of most parts follow the bathtub curve shown in Figure 10. The first part of the curve, the infant mortality region, shows that there is a large amount of failures at the beginning of the life of the part. These failures are caused by manufacturing defects. After this period, the part enters a stable region where random failures occur. This is the useful life of the part. Beyond the useful life of the part is the wear out region where the failure rate increases. Reliability predictions only apply for the useful life of the part and do not account for infant mortality or wear out.

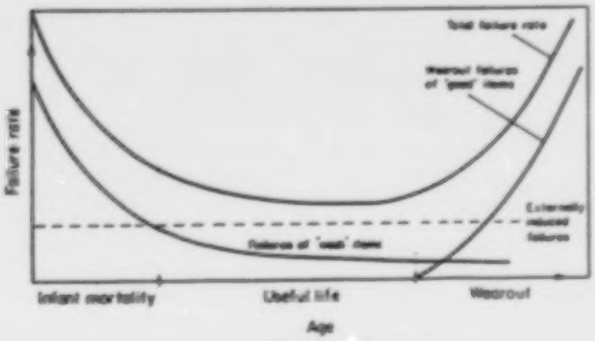


Figure 10 **Bathtub Reliability Curve**

The multiplex system will require a significantly larger number of electronic components than what is currently used in the coach. It is therefore important that the components be highly reliable so that the overall reliability (and hence maintenance requirements) of the multiplex coach actually improves compared with the present, non-multiplexed, coach. Most reliable manufacturing operations address the infant mortality problem by burning-in the parts before they are released to the customer.

Figure 11 shows the reliability requirements for a multiplexing system with identical nodes. It can be seen from this figure that higher reliability nodes are required as the number of nodes increases.

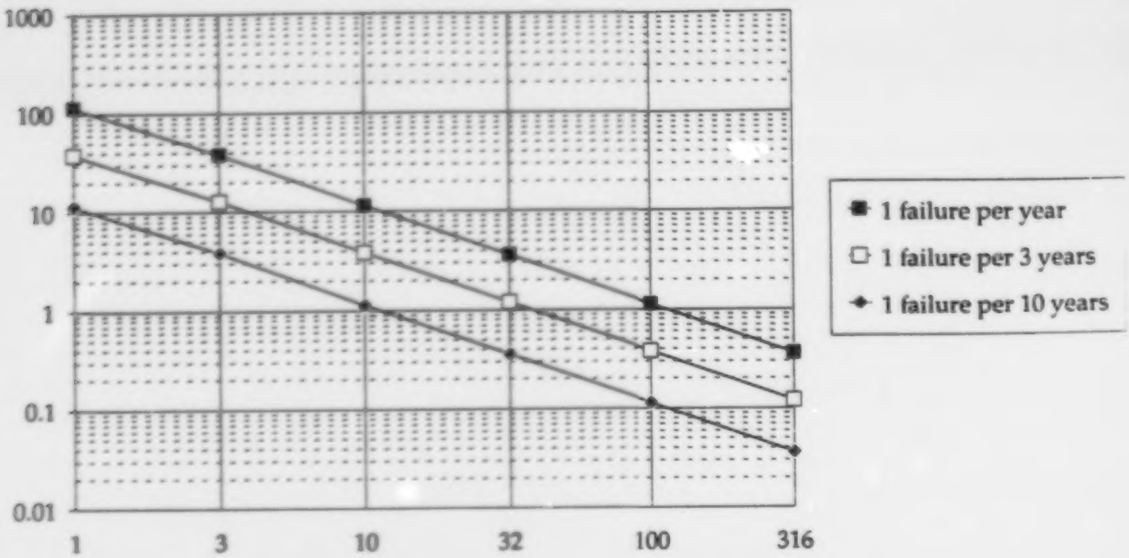


Figure 11 **Allowable Failure Rate per Node vs Number of Nodes.** The chart applies to 24 hour a day operation, 365 days a year. For lessened operation, the allowable failure rate per node can be scaled up accordingly.

It is necessary to approximate the reliability of the multiplex components to effectively address the various economic issues affecting the overall cost/benefit of the multiplex system. MIL-HDBK-217 provides a relatively simple estimation for reliability based on generic parts count. A listing of the various generic part types and their reliability are shown in Table 5. From this the reliability of different part classes can be compared.

The closest environmental factors in the military specifications which match the coach application are either the "Ground, Mobile" (GM) or the "Ground, Fixed" (GF) environment. The "Ground, Mobile" environment applies to equipment installed on wheeled or tracked vehicles. The vibration on a tracked vehicle is more severe than that encountered on the coach. The "Ground, Fixed" environment applies to installations in unheated buildings, but has no provision for vibration. The environmental factor for the coach will be somewhere between these two extremes.

Table 5 **Generic Reliability Prediction of Some Common Components**
(from MIL-HDBK-217E, October 1986.)

	Failures in 1,000,000 hours			
Device Type	Hermetic Package		Non-hermetic Package	
	GF	GM	GF	GM
UVEPROM, EEPROM (bytes):				
<=2K	0.0674	0.0987	0.1282	0.1997
>2K - 8K	0.115	0.1642	0.2366	0.3662
>8K - 32K	0.1998	0.2778	0.443	0.6818
>32K - 128K	0.3861	0.5329	0.8725	1.3409
MOS Microprocessors:				
8 bit	0.0645	0.1069	0.0983	
16 bit	0.1257	0.1967	0.1865	
Bipolar and MOS Linear Devices				
1- 100 Transistors Bipolar	0.0229	0.0358	0.0374	0.0612
1- 100 Transistors MOS	0.0229	0.0358	0.0374	0.0612
>100 - 300 Transistors MOS	0.0377	0.0579	0.0666	0.1086
>100 - 300 Transistors Bipolar	0.0377	0.0579	0.0666	0.1086
>300 - 1000 Transistors Bipolar	0.0653	0.0989	0.1231	0.2002
>300 - 1000 Transistors MOS	0.0653	0.0989	0.1231	0.2002
Logic				
1- 100 gates Bipolar	0.0211	0.0331	0.0222	0.0349
1- 100 gates MOS	0.0222	0.0349	0.0323	0.0517
>100 - 1000 Gates Bipolar	0.0368	0.0573	0.0391	0.0608
>100 - 1000 Gates MOS	0.0391	0.0608	0.0593	0.0945
>1000 - 3000 Gates Bipolar	0.0704	0.1094	0.075	0.1164
>1000 - 3000 Gates MOS	0.075	0.1164	0.1155	0.1837
>3000 - 10000 Gates Bipolar	0.2427	0.39	0.2519	0.4039
>3000 - 10000 Gates MOS	0.2519	0.4039	0.333	0.5386

Table 5 (cont) Generic Reliability Prediction of Some Common Components

	Failures in 1,000,000 hours	
Device Type	GF	GM
NPN Discrete Transistors	0.016	0.063
PNP Discrete Transistors	0.025	0.098
Film Resistors (RNR type)	0.0037	0.014
Composition Resistors (RCR type)	0.0021	0.011
Ceramic Capacitors (CKR type)	0.0059	0.03
Solid Tantalum Capacitors	0.014	0.055
Dry Aluminum Capacitors	0.29	2.6
Inductors	0.0066	0.026
Relays:		
General Purpose	0.32	1.2
Contactor	1	4
Toggle & Push Button Switches	0.0029	0.014
PCB Connector	0.024	0.12
Connections for Circuit Boards without Plated Through Holes:		
Hand solder (no wrapping)	0.00546	0.01898
Hand solder (wrapping)	0.000294	0.001022
Reflow solder	0.0001449	0.0005037
Circuit Board Connections with Plated Through Holes:		
Hand Soldered	0.0024518	0.0082082
Wave Soldered	0.0001886	0.0006314
Other Connections:		
Crimp (hand)	0.001092	0.003796
Crimp (automatic)	0.000546	0.001898
Solderless wrap	0.00000735	0.00002555

The generic part reliability calculation consists of adding up the failure rates of all the parts. The total is the failure rate for the system. This calculation is only good as an estimator for different alternatives and leaves out the effects of how individual components affect the overall operation of the equipment. For example, failure in one component such as a bus transceiver could potentially shut down the whole multiplexed system whereas a failure in another component such as an operational amplifier may cause the loss of data from a non-critical sensor. It is important to expend extra effort and financial resources to achieve enhanced reliability in critical subsystems.

In the detailed design phase, the more elaborate models for the component reliabilities, which take into account their actual operating conditions, will be used. In addition, the effect of a failed component on the overall system will be evaluated.

From the table we see that it is important to keep the number of circuit board connections low, especially if hand-soldering is being used on non-plated through holes. Connections made with reflow soldering are very reliable. Single sided surface mount boards are therefore highly attractive in terms of reliability and economy (typically 100 of these connections are comparable in reliability to a discrete component). It is also important to notice that seven or eight microprocessors will fail as often as one relay. The use of generic disposable nodes, fully solid–state and hermetically encapsulated, will greatly enhance reliability.

It is recommended that a more thorough investigation of the reliability models be performed before the detailed design proceeds in order to maximize the initial design reliability. It should be noted that standard derating guidelines exist for reliable electronic design.

Initial reliability investigations show that a Class B node has a reliability of approximately 1 failure in 1,000,000 hours (roughly equivalent to the reliability of a single relay).

4.2.1. Semiconductor Reliability

It is important that semiconductor devices are not stressed beyond their recommended limits. In particular, breakdown voltages, junction temperatures and maximum current limits must be adhered to. Adequate design margin should be provided on these limits and the devices will be more reliable when larger margins exist. Adhering to standard derating guidelines will provide the necessary design margin.

Hermetically sealed (ceramic, for example) semiconductor devices do not suffer from moisture related wearout mechanisms. Plastic encasing is not a hermetic sealing process, but semiconductor manufacturers have developed processes to improve the plastic encapsulation material such that moisture-related failures have been drastically reduced (it should be noted that the reliability prediction data from MIL-HDBK-217E is from October 1986 and some of these improvements have been made since then). It is necessary to weigh the cost/reliability issues for plastic and ceramic semiconductors when designing the multiplex nodes.

Purchasing burned-in parts can eliminate devices with manufacturing defects. The infant mortality period in one semiconductor data book is defined as being 168 hours, with 75% of the defective parts failing within the first 48 hours (AMD, PAL 1990 Data Book). The use of burned-in semiconductors is advantageous and many vendors offer this feature.

4.2.2. Enhancing Reliability

Parts selection is important in enhancing reliability and devices causing the worst potential failures should be as reliable as possible. The overall reliability of the coach can be further improved by incorporating various fault tolerant schemes such as redundancy. Also, the ability to detect minor faults and correct them quickly will prevent more major faults from occuring. Fault tolerance is discussed in more detail later in the report.

4.3. Fault Tolerance

4.3.1. Introduction

Fault tolerance is the ability of a system to remain functional in the presence of one or more failures. Faults are inevitable since components eventually fail and undetected communication errors can exist.

When a component fails it is important that the vehicle remain functional so that the passenger safety and convenience is not jeopardized.

The fault tolerance requirements on an intercity coach are more demanding than those on trucks or automobiles since more people are involved. Potentially, a breakdown during a trip could result in a lawsuit.

4.3.2. Types of Faults

Faults range in severity and can be classed as follows:

- faults which threaten life and safety;
- faults which cause vehicle immobility (this type of fault may or may not result in vehicle damage);
- faults which cause minor inconvenience (e.g., a light cannot be controlled, or the vehicle functions at reduced performance).

Efforts to provide fault tolerance must be expended according to the severity of the fault.

4.3.3. Simultaneous Faults

Systems can be designed to cope with single or multiple faults. The cost of the design and equipment increases with the number of faults which can be tolerated.

The probability of a single fault occurring is low. The probability of an additional fault occurring simultaneously, which can augment the destructive potential of the first one, is much lower. Thus designing to cope with the first level faults is often sufficient.

Faults which are detected should be immediately reported. If a fault is detected early enough, corrective action can be taken to prevent it from becoming more serious.

4.3.4. Fault Detection and Isolation

To provide effective fault tolerance, both fault detection and isolation must be present.

Faults can easily be detected, but there also has to be means for isolating them from the system in order to achieve fault tolerance. For example, a bus failure can be detected but if a redundant bus is not present, or there is no means of switching out the defective bus section, the system is rendered inoperative.

4.3.5. Fault Tolerance of Multiplexing Classes

4.3.5.1. Class A

Some faults only cause minor convenience. Other faults threaten life; e.g., the door opens while the vehicle is at highway speed or the headlights shut off during night driving. Even a driver's window defroster failure can be serious.

Devices must assume a default state which is safe in the event of failure (i.e., the headlights should default to being turned on). Other devices, such as the entrance door, may require a manual override.

4.3.5.2. Class B

If Class B is used for information transfer to the dash, and providing diagnostics, fault tolerance is not as critical.

The most serious failure that can happen is that the driver loses feedback from the rest of the coach. Vehicle damage could occur if another fault, such as the engine overheating, occurs simultaneously with the loss of the engine overheating tell/tale.

When Class A data and real time control data is being carried by the Class B bus, the fault tolerance requirements become more severe since the potential to threaten life or cause vehicle immobilization is present.

4.3.5.3. Class C and Control Data

Vehicle immobilization can easily result from a failure in a Class C bus (e.g., if link between the throttle and the engine is lost, there is no way to command the engine speed). Additionally, life threatening situations can result from failures in systems controlling brakes and steering.

Subsystems should default to a reduced functional capacity state that is safe.

4.3.6. Potential Multiplex System Faults and Means to Combat Them

4.3.6.1. Bus Shorts and Opens

General

A bus short or open can occur from cable strain, or improperly applied connectors or cable fasteners. The failure of a major bus (except when it is being used for information transfer only) will, at a minimum, result in total vehicle immobilization.

Thick cable jackets and high quality connectors and fasteners can be used to help prevent faults from occurring.

Single Line Faults

Class B and Class C busses typically use twisted pair wire. A short or open on a single line can be detected and isolated electronically. The noise isolation of the bus is degraded when operating from a single line, but it is still useable.

Detection of a single line failure can prevent the more serious situation when both lines fail, provided the failure is reported and corrected before the second line fails.

Another method to tolerate single line faults is to use ac-coupling on each line so the receivers can re-bias themselves in the event of line failure. With this method, the fault can go undetected by the system and this may lead to more serious failure. Electronic detection and isolation is preferred since it can be integrated into the interface IC and it allows NRZ data to be used which is more bandwidth-efficient than data without a dc component (Philips CAN ICs will incorporate this feature).

Double Line Fault

If both lines of the multiplexed bus are shorted to battery or ground the bus is rendered inoperative. (A short between the lines can be detected electronically and the receiver and transmitter circuitry can be converted to single-ended operation to retain functioning, but this is generally not done).

There are several ways to combat an inoperative bus. One is to use a redundant bus as is done with MIL-STD-1553. This requires extra cabling and a duplicate set of transmitters and receivers at each node. Another approach is to connect the ends of the bus together to form a ring. This is being done in several automotive systems and prevents opens from isolating sections of the bus.

For short circuit prevention, the nodes can be designed as shown in Figure 12. Here the node has the ability to switch out the shorted bus section. When a short circuit occurs, each node can, in turn, open the switch and see if the bus returns to operation. Eventually the short can be isolated automatically by the system.

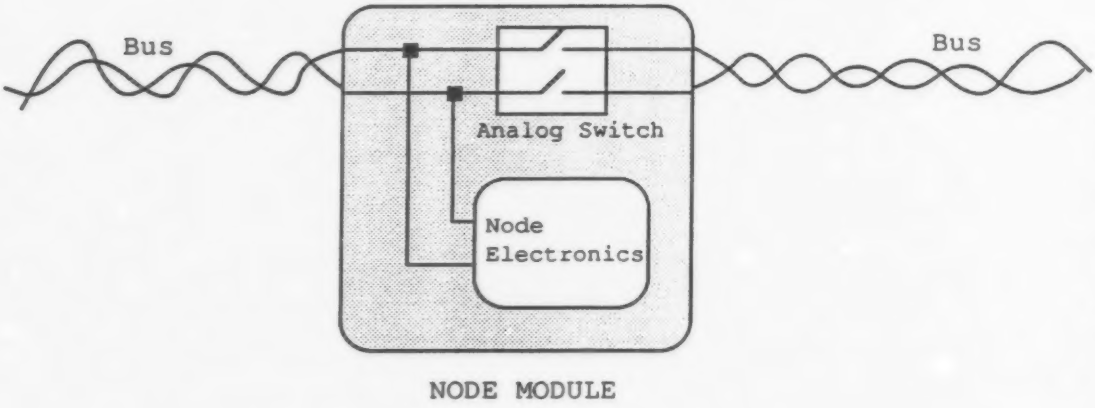


Figure 12 **Short Circuit Protection & Isolation**

An additional advantage is that the section of failed line can be identified to the maintenance personnel (normally, a short circuit on a bus is difficult to locate). A disadvantage is that the bus requires two pairs of connection points and a switch at each node. The extra components reduce the initial reliability.

4.3.6.2. Continuously Active or Failed Node Transceiver

The continuously active or failed node transceiver can cause loss of the bus. In MIL-STD-1553, the transceivers are coupled to the buses through resistors and transformers. The resistors prevent a shorted transformer from shorting out the bus. This idea can be used for the transceivers. The resistors are also useful for providing some RC filtering to improve the noise immunity as is done in J1708 (see Figure 6). Continuously active transmitters can be handled using a failsafe circuit which disconnects the transmitter if it detects transmissions longer than a preset limit.

A failure in a node receiver can cause the node to jam the system by constantly negatively acknowledging transmissions. Algorithms exist for a node to detect when it causes more negative acknowledges than other nodes so it can take itself off the network [7].

4.3.6.3. Node Failure

Node failures can cause loss of sensor data or loss of output control. Outputs (including the node transmitter) must default to their safest state, and other nodes in the system must resort to other means to replace the lost sensor data. These include using data from alternate sensors (calculations may be required), or assuming a safe default value. Manual override should exist for outputs which control exit doors or cause major inconvenience.

With a distributed system, it is possible for other nodes to cover up for a failed node. For this to work the other nodes must have access to the critical sensors or critical outputs of the failed node.

4.3.6.4. Sensor Failure

Sensor failure is not usually critical. The most serious failure is likely the loss of the speedometer. A failed limit switch could also be a problem.

If the sensor failures are corrected immediately, it is unlikely that an associated second level fault will occur. For example, if the engine temperature sensing unit fails there is still a good chance that the engine will not overheat before service can be obtained. A failed temperature sensor does not warrant shutting the vehicle down.

Sensor failure can be handled by having redundant sensors or by approximating the sensor output (by calculation, or using other sensor data). Sometimes it is possible to ignore the failed sensor and accept the reduced functionality or risk imposed. It is important that the failed sensor be detected and reported to the driver (or to service personnel when the vehicle enters the bus depot), so that immediate servicing can be obtained.

4.3.6.5. Power Switch Failure

Most power switch failures can be tolerated until the next servicing opportunity. The multiple power switches used in the multiplex system can provide fault tolerance advantages over existing systems. For example, a separate power switch used on each headlight prevents both headlights from failing simultaneously due to a failure in a single power switch.

Device failure modes should be directed to safe operating conditions (e.g., if the input circuitry open circuits, bias resistors should be used to force the device to a safe state).

Redundant switches are easy to implement since the power switches source or sink current, but not both. They can easily be connected in parallel. An extra switch in a quad power switch device could be used for this redundancy.

4.3.6.6. Dash Display Failure

A failure in the dash display can cause total loss of driver feedback. Failure in a dash switch module can prevent control of a set of subsystems.

Redundant displays and switch panels can be used to advantage. For example, if the dash display fails, relevant information or graphically constructed gauges can be displayed in the message area on the switch panels instead. The existence of two switch panels allows for the functionality of one panel to be taken over by the other . A bank select switch or a denser display can be used until servicing is obtained.

4.3.6.7. Power Failure

Power failure can occur from a tripped circuit breaker or broken wire. To provide fault tolerance against power failure, nodes should be wired to different power sources wherever possible. This is especially important for the dash components so that in the event of a failure, at least one display is available to notify the driver of what has gone wrong.

4.3.7. Maintenance Requirements

Coaches must be repaired and serviced almost anywhere on the continent. The various service and repair depots must therefore be equipped with the required equipment and personnel to service the vehicles. Servicing must be efficient in terms of time and cost. The Mean Time to Repair (MTTR) must be low.

In order to satisfy these requirements, the coach must be designed such that it is straightforward to diagnose and maintain.

Multiplexing will introduce more electronic circuitry into the coaches. The maintenance depots are already being forced into handling a greater variety of electronic subsystems on the coaches due to the use of DDEC and ATEC. The future ABS/TC will also require electronic servicing.

The required servicing for the multiplexed system must be available by the time the first coach with multiplexing is introduced into the market. Introducing electronic products into the market without serviceability creates nightmares as did the FMVSS-121-mandated governmental standard for anti-lock brakes [9]. A detailed maintenance strategy will have to be developed to ensure that this doesn't happen with the introduction of multiplexing.

4.3.7.1. Equipment Requirements

Diagnostic Tester

It is important that a generic type of diagnostic tool be used to service the vehicles; otherwise the service depots will be required to own a large number of different testers. The likelihood of the service depot having a particular tester is directly proportional to how compatible that system is with other predominant systems on the market.

It is inadvisable to get into the situation where specialized testers have to be supplied to the various service depots for different subsystems on the coach. A generic PC-based tester would be ideal, and will likely become more popular in the future.

In the United States, the SAE J1587 Recommended Practice addresses the subject of diagnostics and attempts to define a standard for message and data formats. In Europe, the ISO 9141 (1989) Standard tries to address hardware issues relating to the diagnostic testers.

As defined by ISO 9141, any diagnostic communication is expected to fulfill one or more of the following aims:

ISO 9141 Diagnostic Communication Aims

- to determine of a system is functioning correctly;
- to carry out an inspection;
- to locate deviations from specification and achieve economic repair;
- to confirm a system has been restored to correct operation;
- to reset or adjust system operating values in an Electronic Control Unit (ECU) in strict accordance with the vehicle manufacturer's instructions;
- to give recorded information related to service activities.

In order to accomplish these aims, the diagnostic instrument must be able to receive information from any node on the multiplexed system, as well as being able to send commands to any of these nodes.

4.3.7.2. Receive Information from any Node

Having the capability to receive information from any node connected to the multiplex system offers several significant benefits for efficient maintenance and diagnosis:

Benefits of Receiving Information from any Node

- existing components can be automatically identified, checked, and logged. This includes version and lot numbers for upgrade purposes. Versions slated for recall by by manufacturers can easily be identified automatically
- sensor data can be acquired and checked for accuracy and validity
- operating parameters can be checked, tested, and logged
- archived diagnostic information can be easily obtained

4.3.7.3. Send Commands to any Node

Being able to send commands to various nodes also has several distinct advantages:

Benefits of Sending Commands to any Node

- automatically verify proper node operation and responses
- automatically program nodes with different operating parameters

Now, service personnel need not physically test nodes for proper operation. The testing can be done through software resident on the coach or in the diagnostic tester. Service personnel can be prompted through a short series of tests to verify proper node operation. Results, prompts, and input can be provided either by the diagnostic computer, or the coach dash.

Equipment for Isolating Data Bus Shorts

If the data bus is wired in a continuous fashion between nodes (using insulation displacement connectors, for example) it will be very difficult to isolate a bus short using conventional trouble shooting equipment. The best way to isolate a bus short is to inject a current into the bus and use a hall effect device to determine the direction in which the current is flowing. Alternatively, a microvolt meter can be used to determine the direction of the current.

Additional circuitry can be incorporated in the multiplexing system to facilitate the detection of shorts, but this may not be warranted since the shorts are likely to occur vary infrequently in a properly designed system.

Training Requirements

Training requirements can be reduced using a PC-based tester with appropriate software.

4.3.8. Diagnostic Requirements

Diagnostic requirements are increasing as electronic equipment becomes more and more prevalent in the intercity coaches. The electronic equipment itself is very reliable, but at the same time it allows the addition of diagnostic capabilities previously not possible. Manufacturers and consumers in this field are becoming aware of the benefits of increased diagnostics. However, there must be some standardized means of making this information available to the outside world.

It is important to be able to track both intermittent as well as constant failures. The lack of being able to track intermittent failures can cause extremely high trouble-shooting expenses and may make it impossible to correct such faults. Fortunately, this data can be logged in non-volatile memory for access by service personnel.

The multiplexing environment facilitates the handling of diagnostic information. Not only can information be provided to a mechanic, but can also be provided to the driver at appropriate times.

Since the coach incorporates subsystems from many vendors it is important that the vendors support a common communication protocol and represent the data in the same format. Otherwise, a proliferation of diagnostic equipment will be required to diagnose all the coach systems.

The SAE Truck and Bus Subcommittee has recognized the seriousness of this situation and has introduced the SAE J1587 document to standardize on protocol and data formats. They have also defined a set of standardized diagnostics [9]. A list of their diagnostic identifiers are shown in Table 6.

Table 6 **FMI (Failure Mode Identifier) Diagnostics for J1587**

FMI	Description
0	Data valid but above normal operational range
1	Data valid but below normal operational range
2	Data erratic, intermittent, or incorrect
3	Voltage above normal or shorted high
4	Voltage below normal or shorted low
5	Current below normal or open circuit
6	Current above normal or grounded circuit
7	Mechanical system not responding properly
8	Abnormal frequency, pulse width, or period
9	Abnormal update rate
10	Abnormal rate of change
11	Failure mode not identifiable
12	Bad device or component
13-15	Reserved

4.3.8.1. Sensor Diagnostic Requirements

With existing systems it is difficult to determine when a sensor has malfunctioned, since data can still be read from it. With the node controllers present in multiplex system, it is possible to improve sensor data reliability using redundancy or calculating expected results based on other available sensor data or known sensor performance.

One possible technique for incorporating redundancy, is to use two sensing elements in a single sensor package. Alternatively, two separate sensors can be used. The node controller can check for consistency between the two outputs. If a discrepancy is detected, the system can handle the data with caution and report the sensor failure. This type of sensor can also eliminate the time-consuming task of verifying the sensor output against a variety of operating conditions since the sensor can be designed so that it is unlikely that both outputs track in a failed condition.

4.3.8.2. Subsystem Diagnostic Requirements

The vehicle can be implemented with additional sensors to provide a better indication of the performance of various subsystems. A detailed cost/benefit analysis should be performed for each potential application to compare the maintenance savings with the cost of installing the additional sensors. For example, pressure and temperature transducers can be incorporated in the HVAC system to determine the functionality of the expansion valves. This prevents gauges from being installed on the vehicle during maintenance and causing potential freon loss.

Differential pressure sensors can be installed across filters to determine when they require attention. This can save maintenance costs by having the filters serviced only when necessary. Some of these features have been addressed by J1587 as shown in Table 7.

Table 7 Differential Pressure Diagnostics for J1587

Parameter Description	Purpose
Fuel Filter differential pressure	determine if fuel filter should be replaced
Particulate Trap Inlet Pressure	determine if exhaust filter should be replaced
Engine Oil Filter Differential Pressure	determine if oil filter should be replaced
Air Filter Differential Pressure	determine if air filter should be replaced
Coolant Filter Differential Pressure	determine if coolant filter should be replaced

Temperatures of axles and bearings can also be monitored to potentially detect failures in their infancy. This is also supported by J1587. In the future sensors which detect debris in the oil, for example, can also be used to reduce maintenance costs.

4.3.8.3. Identification Diagnostic Requirements

For maintenance purposes, it is important to know the manufacturer, model number, revision level, serial number, etc., of the equipment on the multiplexing bus. This is particularly important when a large amount of OEM equipment is being installed on the coach since MCI has no control over the long term quality of the parts which are supplied to them.

It is therefore important to be able to efficiently detect the presence of potentially faulty components installed on the coach.

Having the component IDs programmed into the devices saves manufacturing costs because of the reduced labelling requirement of the devices. It also saves maintenance costs because the service technician does not have to physically examine the individual parts to determine their acceptability. In fact the diagnostic tester can be programmed to automatically check the equipment contained on the coach against a list of faulty parts and advise the technician to change the parts on the coach which match the list. It can even tell him where the parts are located, and how to access and replace them.

The list of faulty parts can be transferred to the diagnostic computer via modem or by disks circulated monthly by the manufacturers. Alternatively, information from paper bulletins can be entered into the computer's data base by the service personnel themselves.

The SAE J1587 supports identification parameters. Every subsystem installed on the coach will have its proper, unique identification.

4.4 Transparent Expansion/Reduction Requirements

Transparent expansion/reduction is the ability to expand or reduce the multiplex system without affecting its operation.

Transparent expansion/reduction is important for the following reasons:

- a large number of options and specials are used on the coach, and equipment varies from coach to coach;
- it is desirable to take advantage of new equipment as it becomes available with minimum design effort; and
- it is desirable to support field upgrades by personnel with little or no knowledge of the multiplexing system.

A well-implemented transparent expansion/reduction scheme can improve fault tolerance; i.e., removing a node is similar to a node failing.

Two levels can be considered with transparent expansion/reduction:

- a lower level, where the network is not affected by the addition and removal of nodes; and
- a higher level, where the system can take advantage of new features as they are added and provide operational contingency as features are removed.

The requirements of the lower level transparent/expansion reduction are predominantly hardware-oriented. The higher level requirements require the same hardware but more sophisticated software. The higher level transparent expansion/reduction scheme is more important to MCI since it can facilitate the handling of options and specials.

4.4.1 Hardware

In order to achieve transparent expansion/reduction, the following hardware criteria must be satisfied:

- the bus must be able to accommodate more nodes;
- the bus must be able to be extended or reduced in length;
- bus connections must be simple to add or remove; and
- driver and maintenance interfaces must be able to adapt to new subsystems.

4.4.1.1 Adaptable Driver Interface

When new systems are added to the coach they may require driver activation or provide information for the driver to use. The hardware in the dash must be capable of accommodating subsystem changes.

One way of doing this is to add additional equipment in the dash such as a new switch or tell/tale each time a new subsystem is introduced. Another way is to change the faceplates of existing devices.

A better approach, however, is to implement the driver interface with a character or graphics display with associated touch screen or push buttons. The driver interface can than adapt automatically, without any hardware modifications, to the system changes.

4.4.2 Software

For the high level expansion/reduction scheme, the software must be capable of taking advantage of new features and providing contingency operation. The following software requirements must be met:

- a standard driver interface is required;
- a standard node to node interface is required;
- data must be compatible so it can originate from multiple sources;
- software must be capable of selecting data from multiple sources; and
- a standard maintenance interface and diagnostic protocol is required. This is supported by J1587.

The key to implementing this software is a well-organized plan and an accurate anticipation of what future subsystems will exist. The coordinators for J1587 and J1922 appear to be proceeding in this direction.

4.4.2.1 Standard Driver Interface

The driver interface must be structured so that proper driver control and driver feedback is provided for each subsystem.

When the multiplex system is initialized, each subsystem (node) can notify the dash controller of its driver interface requirements so that the proper controls and driver feedback are displayed.

The software in the dash must be capable of organizing the switch panels and formatting the driver messages.

4.4.2.2 Standard Node to Node Interface

Class B and C nodes employ microprocessors, so it is possible for the node control algorithms to adapt to system changes.

As an example, the SAE J1922 specification has initialization messages which inform the various subsystems of the individual subsystem's capabilities. This allows the subsystems to work together in an efficient way (i.e., engines and transmissions of varying varieties and manufacturers can be mixed and matched with J1922).

J1587 supports the use of limit setting parameters which are useful in tailoring the function of OEM equipment to the final application or to restrict potentially dangerous or undesirable driver activities. The current set of limit settings specified by J1587 are shown in Table 8. However, more limit settings can be programmed into the various device nodes as needed.

Table 8 Current Limit Settings Specified by J1587

Parameter Description	Purpose
Maximum Road Speed Limit	Sets the maximum allowable vehicle velocity
Cruise Control High Set Limit Speed	Sets the maximum allowable speed at which cruise control can be activated
Cruise Control Low Set Limit Speed	Sets the minimum allowable speed at which cruise control can be activated

4.4.2.3 Data Compatibility

Data compatibility concerns itself with data coming from different sources. Specifically, data from two or more sources must be in the same format so that no knowledge of the external systems is required on the part of the dash processor to interpret it.

An example of the data compatibility requirement is vehicle speed information which can be obtained from DDEC/ATEC or from the LH front wheel hub. (ATEC provides a speed sensor output which can be converted to road speed by DDEC.)

On coaches with DDEC/ATEC installed, the hub sensor is likely not installed (for economical reasons). The dash processor must therefore be able to recognize that the data is not available from the hub sensor and know to obtain it from DDEC. In order for the data to be useful, it must be in the same format as the hub data.

J1587 supports such operation by defining data formats. Data is identified by a PID (Parameter IDentification code) which, in this example, is the road speed. The source of the data is identified by the MID (Message IDentification code); i.e., either the LH front wheel or DDEC.

The software in the dash processor must be capable of locating all the equivalent PIDs on the system and selecting the data source according to a prioritized preference scheme.

4.4.2.4 Implementing Expansion/Reduction with Custom Programming

An alternate implementation to perform expansion/reduction would be to adopt custom node programming. Custom node programming can be implemented so the system can be programmed during manufacture to take advantage of the available features.

This approach requires less sophistication at the node level, but increases difficulty in handling the software.

This approach is not recommended for the following reasons:

- small capacity semiconductor memories are being phased out so economizing on local node software provides little or no economic benefit;
- it is difficult to handle field repairs unless (1) the node software resides elsewhere in the system, and (2) the nodes can be programmed while installed. Otherwise, software for every option has to be distributed to the service depots or a host of different parts has to be issued;
- it is difficult to handle the code selection for the various nodes during manufacture -- an automated system is required to prevent error.

4.5 Data Transmission Requirements

For a multiplex system, the form of data transmission is largely determined by cost considerations. There are many different ways of transmitting data with each having its own advantages and disadvantages. The key is to use the cheapest means available that performs the necessary function.

4.5.1 Conductive Cabling

One of the main disadvantages with transmission over conductive cabling is that transmission line effects become more of a problem as the data rate increases. These effects result from the distributed inductance and capacitance of the cable. Basically, the edges of the waveform are distorted and include high frequency ringing (caused by reflections of the signal from the source and load ends of the line) and vary with the way the load and source impedances are matched to the line impedance. The effects are present on low frequency signals, but because the bit period is so long, they cause negligible loss in the energy of the bit and it is easy to make a decision as to what the bit is. As the bit rate increases, the transmission line effects become more of a significant part of the bit period. It then becomes important to ensure that the loads and driving impedances are well matched to the line impedance to minimize the reflections.

With a bus arrangement, it is very difficult to match the source and load impedances to the line, because there are many sources and loads. Each node which is not driving the line presents as high an impedance as possible, but due to parasitic capacitance, there are limitations to the what the impedance levels can reach. For high frequency transmission, it is best to use point to point communication which is supported by a ring architecture rather than a bus architecture.

Unshielded twisted pair is the preferred medium to use with the existing multiplexing systems since it is low cost and easily terminated. Although coaxial cable and shielded twisted pair can potentially provide more uniform characteristic impedances and better shielding performance, they are not recommended because the cable is more expensive and more expensive to terminate. They can be selectively employed in problem areas should testing prove that the additional performance is necessary.

Mr. Ernie Kuzik with Manitoba Telephone Systems (MTS) has stated that they are using unshielded twisted pair for data transmission up to 10 megabaud. He claims that unshielded twisted pair works better than shielded twisted pair because it is difficult to ensure that the shield is connected properly. If the shield is improperly connected, noise on the line increases above the level which exists for unshielded twisted pair.

4.5.2 Fibre Optics

The predominant fibre optic materials are glass and plastic. The glass fibres are more expensive and are suited for very high data rates over long distances. They are typically small in diameter (60 µm) and difficult to fuse and to terminate. It is also doubtful whether they can handle the vibration environment present in an inter-city coach.

Plastic fibres are more suitable, since they are much less expensive and not as fragile as the glass fibers. They are typically much larger in diameter (1 mm) than glass fibres and easier to work with. However, they are typically restricted to data rates under 5-8 megabaud and distances of less than 40 metres [10]. The attenuation for plastic fibers is very high and it is best to restrict them to distances less than 40 metres for higher noise immunity.

The main difficulty in employing fibre optics with the present bus-based standards is the lack of bus connectors. Even if they were available, the bus connections will attenuate the optical power and erode the signal-to-noise ratio. To combat this, higher power transmitters and lower attenuation fibres are required, increasing the cost. The connectors will also be fairly expensive.

Fibre optics are best used in a ring configuration since then point-to-point communication is used. But, in a ring configuration, the latency for critical data transmission suffers unless the data rate is high (the FDDI Local Area Network Standard provides a ring configuration which uses 125 megabaud data rates. It has low latency but requires expensive hardware and glass fibers to implement it. Two fibres are used for the transmission media with the data circulating in opposite directions. The redundant fibre is useful to combat the failure of one node which would normally bring down a ring network).

4.5.3 Wireless Transmission

The most suitable form of wireless transmission for multiplexing applications is infra-red. This is suited for line-of-sight transmission over short distances (less than ~50 ft.). It could be used to broadcast audio (and possibly video) data in the interior of the coach or to provide the link between an external diagnostic computer and the coaches multiplex system (it is possible for the coach to drive into a depot and have the multiplex system queried by a computer using an infra-red link).

RF transmission could also be used for relaying diagnostic information and provisions are available within the CB-band to accomplish this. RF transmission provides larger range than infra-red but it is more difficult to use due to government regulations. The circuitry is also more complex.

4.6 Architectural Considerations

Current multiplexing protocols use a bus architecture, this section provides some insights as to why a bus architecture is favoured over other architectures.

4.6.1 Distributed and Centralized Architectures

The choice of a distributed or centralized architecture is best made by examining the requirements of the various multiplexing classes.

- **Class A** - Class A subsystems are generally controlled by the driver. Since cost is more of a requirement than speed, the most logical architecture for Class A is a centralized one where an "intelligent" master node controls many "dumb" slave nodes.
- **Class B** - Class B subsystems are involved in sharing information. Each node is "intelligent" and no nodes stand out as being predominant. High priority time-critical data can originate from any node. A distributed architecture is best suited for this class of multiplex system. The network must include a prioritized access mechanism to satisfy latency requirements of critical data.
- **Class C** - Class C subsystems represent high-speed data transfer, distributed processing and real-time control. The same discussion as for Class B applies here.

4.6.2 Architecture Topologies

4.6.2.1 Ring

In a ring, messages circulate to all nodes in one direction. Each node receives all messages and transmits them to the next node. Data rates have to be high to keep the latency time down, because each message must travel around the entire loop. Latency increases as the message passes through each node, because each node must receive at least one bit and decide whether to change its state or not; i.e. for the token. Protocols for ring architectures are fairly complicated, because errors can cause continually circulating messages or loss of the token (a "token" is commonly used to allow a node access to the network). Prioritized access techniques are possible.

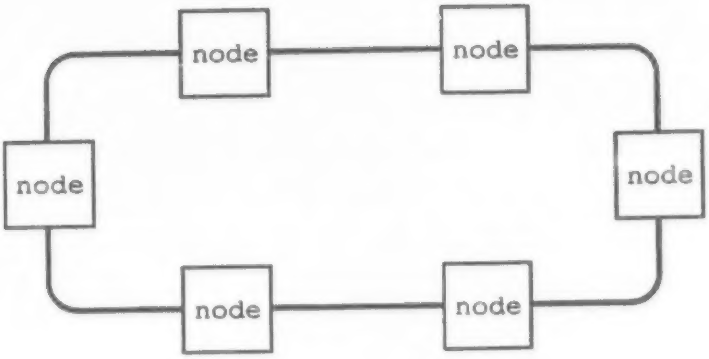


Figure 13 **Ring Architecture**

Figure 13 is a typical ring layout. The main advantage of a ring network is that it uses point to point transmission in only one direction so no adverse transmission line effects occur. The main disadvantages are the latency, and the fact that if a node fails, the entire network is shut down. These disadvantages can be overcome but at more expense.

4.6.2.2 Bus

A bus network is the most flexible architecture. Prioritized access techniques are possible. The main disadvantage for a bus architecture is that the transmitter in each node must be able to drive all the nodes on the bus simultaneously. At low frequencies, this is no problem, but at high frequencies, transmission line effects become a problem. Figure 14 is a typical bus architecture.

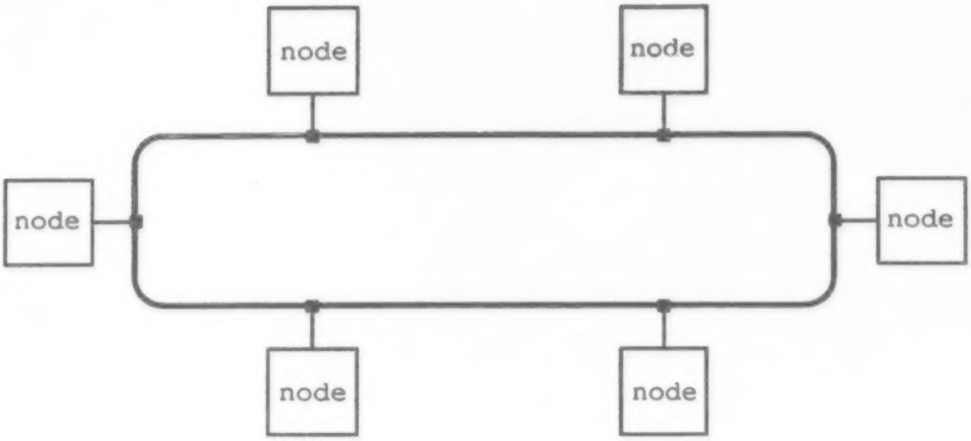


Figure 14 Bus Architecture

To the authors' knowledge, all of the Class B and Class C multiplexing standards available today and proposed for the future are all based on bus architectures. Thus it seems that the bus architecture will have long term support from many independent parties.

4.6.2.3 Star

The star architecture consists of a central "master" node, to which all other nodes are connected. If a node wishes to broadcast to another node, the communication must go through the master node first. The disadvantage of this method is that a fault in the master node can potentially block all communication within the network. Also, due to the large number of wires needed (one set per node), this network is not practical and, in the case of multiplexing, resembles the wiring that it is trying to replace.

Figure 15 is a typical star architecture layout. The star architecture is more useful when all nodes except the master node are "dumb" nodes as in the case of Class A systems.

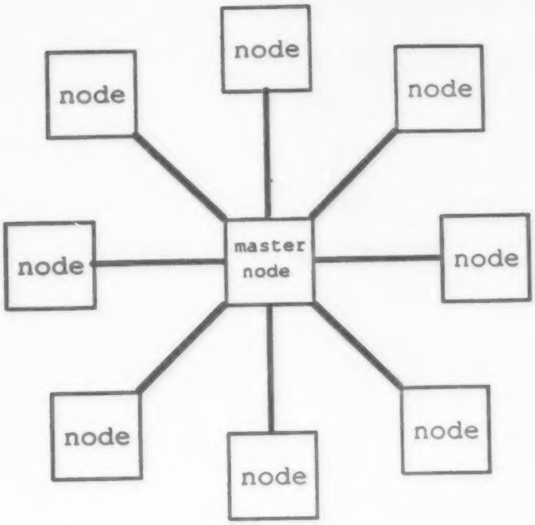


Figure 15 Star Architecture

4.7 Harness Considerations

The packaging scheme must be cost effective with both labour and materials. Currently, a large amount of labour is required to manufacture and install custom harnesses. Generating and handling the drawing control for numerous harness drawings is also expensive. Money can be saved by reducing the number of custom harnesses.

4.7.1 Porcupine Effect

The porcupine effect is illustrated in Figure 16. This easily occurs with multiplexing because a large number of devices typically connect to Class B nodes.

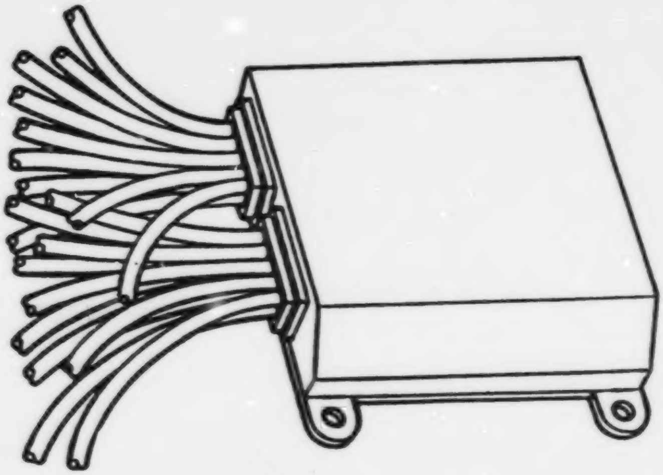


Figure 16 Porcupine Effect

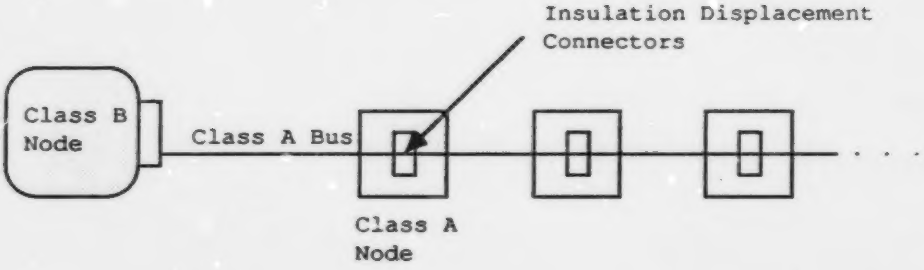


Figure 17 Using Class A Buses to Eliminate the Porcupine Effect

With the porcupine effect comes custom harnesses to implement the connections. The porcupine effect can be eliminated using a Class A bus to connect the devices to the node as is shown in Figure 17.

4.7.2 Node Connections

The connections to the node can be implemented in several ways. The most promising ones are:

- using insulation displacement connectors;
- using studs and ring terminals; or
- using standard bus cables of varying lengths.

4.7.2.1 Wiring Using Insulation Displacement Connectors

Insulation displacement connectors can provide a labour efficient means of connecting the multiplexed bus and loads. The bus can be run in a continuous fashion and nodes can be connected to it wherever necessary. Pigtails from existing sensors and loads can be connected directly to the node without an additional connector required.

The reliability of this approach requires verification.

4.7.2.2 Wiring Using Studs and Ring Terminals

This approach is similar to the wiring technique currently used on the coach. This technique is fairly labour-intensive since labour is required to terminate each wire section and fasten the ring terminals to the node.

4.7.2.3 Wiring Using Standard Cable Lengths

This approach requires custom cables to be built which have the same functionality but vary in length. The cables can be mass-produced since a large number of them are required. The cables are also very simple to make so they can be built from scratch for field repairs. If alternating male and female connectors are used, the connectors can be mated to facilitate node removal. Also, trouble shooting short-circuits is easily achieved since the bus can be broken easily at each node.

4.8 Power System Requirements

Currently, the truck and bus industries use 24 V for starting the vehicle engines. The trucking industry typically runs the remainder of the electrical system from 12 V whereas the bussing industry uses 24 V. The main reason for the difference lies in the fact that coaches require significant amounts of power to supply the HVAC system and the interior lighting whereas trucks do not.

In the long term, the automotive industry is considering switching to 24 V. Multiplexing makes better use of the power lines when 24 V is used since more power is available for a given wire gauge. Starting of the vehicle is also improved. Against this direction is the fact that incandescent lights are more reliable when constructed for 12 V instead of 24 V.

4.8.1 Requirements for Powering the Multiplex System

Multiplexing will eventually become fairly widespread in the automotive industry, and highly integrated multiplexing components will be designed to operate over the worst case automotive power supply requirements. The transient protection requirements for heavy duty vehicles are more severe than for those of automobiles (due to the larger batteries, larger power components and longer wire lengths) and will likely preclude the use of automotive components which are intended for direct connection to the vehicle power. However, some components may have adequate margin to make them suitable for heavy-duty vehicles.

Most digital logic components and existing multiplexing interface components operate at 5 Vdc. Sourcing them from 24 Vdc using linear voltage regulators is inefficient, generates more heat, and shortens the expected life (thus reducing reliability).

12 Vdc appears to be a good choice for powering the multiplexed system since the coaches will eventually have a separate 12 V system and automobiles may never convert to 24 V operation.

4.8.2 Power Wiring Considerations

With Class A multiplexing, the power can be distributed in a more organized fashion. Power wiring no longer has to emanate primarily from the switches on the dash or relays in the junction boxes, but can be distributed according to the load requirements. However, a limitation is reached which is imposed by the size of wire used in the branch circuits. Fuses or circuit breakers must protect the smallest wires used and it is not desirable to do the final connections at the devices with heavy wire.

Table 9 is a table of various wire gauges. 14 AWG is probably the best wire size to use for connection to the devices, since it can handle reasonable current levels and yet is flexible enough to work with. Insulation displacement connectors are available. Since stranded wire is used on the coach, heavier wires such as 10 AWG or 12 AWG might also be acceptable but it is unknown whether a source for insulation displacement connections for these wire gauges is available.

Table 9 Wire Gauge Information

Wire Gauge (AWG)	Ampacity (CSA) (Amps)	Current Causing 0.5V Drop in 10m (Amps)	Cost/m (US$/m)	Resistance (mohm/m)	Cost/ft (US$/ft)	Resistance (mohm/ft)
4/0	235	315.1	$10.30	0.159	$3.14	0.0484
3/0	210	249.8		0.200		0.0610
2/0	185	198.3	$3.18	0.252	$0.97	0.077
1/0	155	157.3	$2.33	0.318	$0.71	0.097
1	140	124.7		0.401		0.122
2	120	98.9		0.506		0.154
3	105	78.4	$2.00	0.637	$0.61	0.194
4	85	62.2		0.804		0.245
6	65	39.9		1.254		0.382
8	45	24.6		2.032		0.619
10	30	15.5	$0.26	3.23	$0.08	0.985
12	20	9.7	$0.20	5.15	$0.06	1.57
14	15	6.1	$0.180	8.15	$0.055	2.48
16		3.8	$0.092	13.0	$0.028	3.96
18		2.4	$0.059	20.8	$0.018	6.34

5. COACH REQUIREMENTS

MCI coaches come in a variety of sizes and with many different options and specials. The coach requirements are determined by analyzing the 102C3 coach. Commonly used options and specials have also been considered.

Currently, the coach requirements can be grouped into the broad range of Class A and Class B data. At present, there is no discernible Class C requirements for the intercity coach other than that required for interactive control between the engine, transmission and future antilock braking/traction control system. But even in this case the data rate requirements are low enough to be handled by a J1708 link. Future requirements will include both a greater number and variety of Class A and Class B data. As well, some other Class C requirements (such as active suspension) may surface.

Future coach requirements presented in this report have been extrapolated from the SAE J1587 diagnostic protocol, discussions with MCI personnel, and general perceived trends in both the automotive and trucking industries.

5.1. Driver Control Requirements

All driver control requirements are, by definition, Class A. They are low speed signals which do not have any stringent latency requirements. However, the driver expects relatively immediate feedback to indicate that the desired action has been performed. Table 10 is a listing of the current driver control requirements as well as some possible future control requirements. Repetition intervals are conservative estimates. Although the repetition intervals are typically quite large, the bus bandwidth must still be adequate to provide an acceptably small latency. Typically, responses can have a latency between 0.1 to 0.5 seconds without annoying the driver (the exact maximum latency depends on the type of action, and the circumstance in which it occurs). In this case it is the latency that drives the bandwidth requirements.

Table 10 Driver Control Requirements

Functional Requirement	Data Requirement	Repetition Int.
CURRENT REQUIREMENTS:		
Start Engine	1 bit	1 hour
Activate Master Switch	1 bit	1 hour
Activate Emergency Engine Override	1 bit	1 day
Activate Mirror Heat	1 bit	1 minute
Activate Horns	1 bit	1 minute
Select Hi-Low Ventilation	1 bit	1 minute
Activate Passenger Ventilation	1 bit	1 minute
Activate Driver A/C	1 bit	1 minute
Unload Trailing Axle	1 bit	1 hour
Activate Fast Idle	1 bit	1 hour
Activate Reading Lights	1 bit	1 hour
Activate Passenger Auxiliary A/C	1 bit	1 minute
Activate Emergency Radio	1 bit	1 day
Cruise Control on/off	1 bit	1 minute
Set Cruise	1 bit	1 minute
Resume Acceleration	1 bit	1 minute
Activate Dash Light Bulb Test	1 bit	1 day
Select Passenger Heat or A/C	1 bit	1 minute
Activate Driver's Defroster	1 bit	1 minute
Activate Step Light/Chime	1 bit	1 hour
Activate Entrance Step	1 bit	1 hour
Activate Entry Door	1 bit	1 hour
Activate Kneel Feature	1 bit	1 hour
Activate Galley Power	1 bit	1 hour
Activate Driver's Light	1 bit	1 hour
Activate Clearance and ID Lamps	1 bit	1 hour
Activate Headlamps	1 bit	1 hour
Activate Hazard Signals	1 bit	1 hour
Activate Coach Lights	1 bit	1 hour
Activate Jacob's Engine Brake	1 bit	1 minute
Set Passenger A/C Temperature	10 bits	1 minute
Set Driver A/C Temperature	10 bits	1 minute
Adjust Dash Brightness	8 bits	1 hour
Adjust Gauge Brightness	8 bits	1 hour
Set Windshield Wiper Speed	2 bits	1 minute
Activate Windshield Washers	1 bit	1 minute
Activate Public Address System	1 bit	1 minute
Activate Audio Entertainment System	1 bit	minute
Adjust Audio System Volume	8 bits	1 minute
Activate Video Entertainment System	1 bit	1 minute
Adjust Driver's Left Blind (stop/up/down)	2 bits	1 minute
Adjust Driver's Centre Blind (stop/up/down)	2 bits	1 minute
Adjust Driver's Right Blind (stop/up/down)	2 bits	1 minute
Adjust Destination Sign (stop/up/down)	2 bits	1 hour
Activate Baggage Compartment Locks	1 bit	1 hour

5.2. Driver Feedback Requirements

The driver must be kept constantly aware of several important coach operating parameters such as vehicle speed, and air system pressure. As well, the driver must be made aware of any system malfunctions when they occur. These parameters are typically provided by various sensor devices or can be calculated by controllers on the multiplexed system and are representative of Class B data. Latency requirements for this type of data are generally not critical.

Single-bit data types can use tell-tale indicators for the driver interface, while multi-bit data types require some form of analog or numeric gauge display for adequate operator interpretation. Many of the future requirements are diagnostic in nature. Critical parameters can be displayed in gauge format on a graphics display when a malfunction occurs.

Latency times of 0.1 seconds should be acceptable to the driver.

Table 11 **Data Requirements for Driver Feedback.** During normal operation, the driver only views the essential data. Other information is displayed as necessary when a system failure occurs.

Functional Requirement	Type	Data Req.	Rep. Interval
CURRENT REQUIREMENTS:			
GAUGES:			
Road Speed	gauge	10 bits	0.1 second
Oil Pressure	gauge	10 bits	0.1 second
Fuel Level	gauge	10 bits	1 second
Battery Voltage	gauge	10 bits	0.1 second
Coolant Temperature	gauge	10 bits	0.1 second
Engine RPM	gauge	10 bits	0.1 second
Air Pressure	gauge	10 bits	0.1 second
Transmission Temperature	gauge	10 bits	1 second
Tachometer	guage	10 bits	0.1 second
TELL/TALES:			
LH Turn Signal	tell-tale	1 bit	0.5 second
Not Gen.	tell-tale	1 bit	1 month
A/C Malfunction	tell-tale	1 bit	1 month
Low Water	tell-tale	1 bit	1 month

Starter Alert	tell-tale	1 bit	1 month
Lav. Emerg.	t-t/buzzer	1 bit	1 day
Jacob's Brake	tell-tale	1 bit	1 minute
Air Filter Restriction	tell-tale	1 bit	1 month
115 Volts Power	tell-tale	1 bit	1 hour
12 Volts Power	tell-tale	1 bit	1 hour
Baggage Locks	tell-tale	1 bit	1 hour
Check Transmission	tell-tale	1 bit	1 month
Check Engine	t-t/buzzer	1 bit	1 month
Stop Engine	tell-tale	1 bit	1 month
Hot Engine	t-t/buzzer	1 bit	1 day
Low Oil	tell-tale	1 bit	1 day
Fire Alarm	t-t/buzzer	1 bit	1 month
Low Air	tell-tale	1 bit	1 month
Hot Transmission	tell-tale	1 bit	1 day
Park Brakes	tell-tale	1 bit	10 minutes
Stop Lamps	tell-tale	1 bit	1 minute
Hi Beam	tell-tale	1 bit	1 hour
RH Turn Signal	tell-tale	1 bit	0.5 seconds
Hazard	tell-tale	1 bit	1 hour
Kneel	tell-tale	1 bit	1 hour
Step Out	tell-tale	1 bit	1 hour
Clear Lights	tell-tale	1 bit	1 hour
Roof Warning Lights	tell-tale	1 bit	1 hour
In-Station Lighting	tell-tale	1 bit	1 hour
Request Stop	tell-tale	1 bit	10 minutes
Retarder Off	tell-tale	1 bit	1 minute
Retarder On	tell-tale	1 bit	1 minute
Backup Lamps	tell-tale	1 bit	10 minutes
Low Air Tag Axle	tell-tale	1 bit	1 month
Low Fuel	tell-tale	1 bit	1 day
Ent. Door Lock	tell-tale	1 bit	1 hour
Retarder Applied	tell-tale	1 bit	1 minute
Retarder Hot	tell-tale	1 bit	1 day

5.3. Diagnostic Requirements

J1587 defines several diagnostic parameters relevant to the coach operation. Table 12 shows a useful subset of these parameters, as well as others that may be required by the coach.

It should be noted that in any future multiplexed coach implementation, most of the future driver feedback requirements listed in Table 12 will typically not be made visible to the driver at any given time. The ideal future dash will display only those parameters of immediate concern to the coach operator. This will prevent information overload.

If the operator wishes to see other operating parameters displayed, he may choose to do so. Additionally, if the coach detects a potential problem, the relevant parameters can be automatically displayed.

Table 12 **Diagnostic Requirements.** These parameters are a modified subset of J1587. The driver need not be aware of many of these parameters and they can remain "hidden" until an emergency occurs, or until the he requests the information. Most of these parameters are useful as diagnostic information during coach operation, and can be automatically transmitted to an on-board data logger.

Functional Requirement	Type	Data Req.	Rep. Interval
Steering Axle Temperature	diagnostic	8 bits	1 second
Drive Axle Temperature	diagnostic	8 bits	1 second
Tag Axle Temperature	diagnostic	8 bits	1 second
Road Surface Temperature	diagnostic	8 bits	10 seconds
Washer Fluid Level	diagnostic	8 bits	10 seconds
Rear Sander Level	diagnostic	8 bits	1 second
Percent Engine Load	diagnostic	8 bits	0.1 seconds
Water in Fuel Indicator	tell-tale	1 bit	10 seconds
Engine Oil Level	diagnostic	8 bits	10 seconds
Coolant Pressure	diagnostic	8 bits	10 seconds
Coolant Level	diagnostic	8 bits	10 seconds
Net Battery Amps	diagnostic	8 bits	1 second
Alternator Amps	diagnostic	8 bits	1 second
Brake Primary Pressure	diagnostic	8 bits	1 second
Brake Secondary Pressure	diagnostic	8 bits	1 second
Transmission Oil Level	diagnostic	8 bits	10 seconds
Transmission Oil Pressure	diagnostic	8 bits	1 second
Alternator Volts	diagnostic	16 bits	1 second
Passenger Compartment Temperature	diagnostic	16 bits	1 second
Driver's Compartment Temperature	diagnostic	16 bits	1 second
Ambient Air Temperature	diagnostic	16 bits	10 seconds
Engine Oil Temperature	diagnostic	16 bits	1 second
Front Axle Weight	diagnostic	16 bits	on request
Drive Axle Weight	diagnostic	16 bits	on request
Tag Axle Weight	diagnostic	16 bits	on request
Trip Fuel	diagnostic	16 bits	10 seconds
Fuel Rate	diagnostic	16 bits	0.2 seconds
Instantaneous Miles per Gallon	diagnostic	16 bits	0.2 seconds
Average Miles per Gallon	diagnostic	16 bits	10 seconds
Tire Temperature	diagnostic	24 bits	10 seconds
Tire Pressure	diagnostic	24 bits	10 seconds
Trip Miles	diagnostic	32 bits	10 seconds
Total Miles	diagnostic	32 bits	10 seconds
Total Vehicle Hours	diagnostic	32 bits	on request
Date	diagnostic	24 bits	on request
Elapsed Time	diagnostic	24 bits	10 seconds
Baggage Doors Unlocked Indicator	tell-tale	8 bits	1 hour

5.4. Power System Requirements

5.4.1. Power Requirements

The bulk of the coach electrical system operates at 24 V. Figure 18 is a general layout of the coach's main power distribution (excluding those which go to the roof) and how they connect to the various junction boxes.

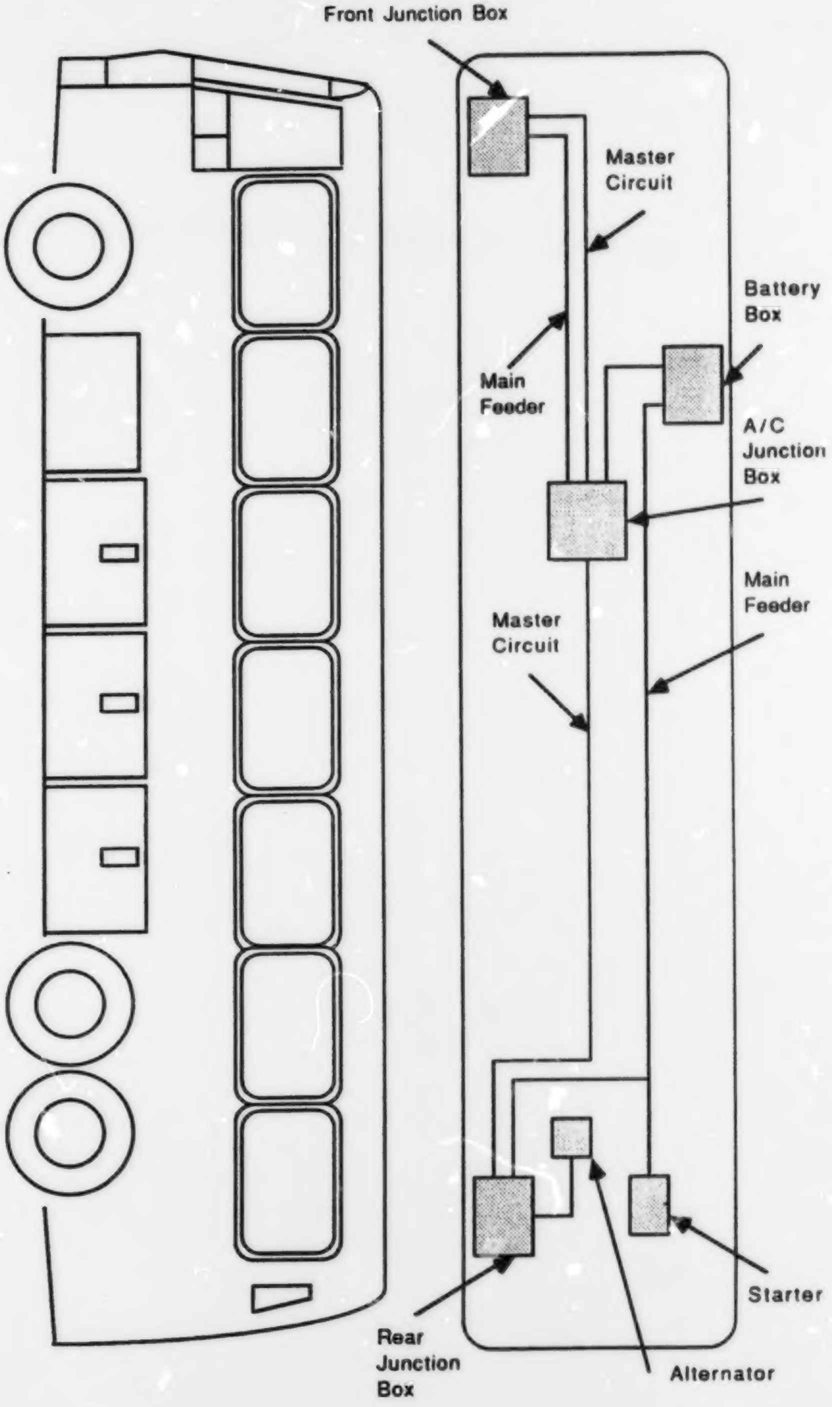


Figure 18 Main 24 Vdc Power Distribution and Junction Boxes

5.4.2. 12 Vdc Power Requirements

Present MCI coaches use 12 Vdc to power the following:

Present MCI 12 Vdc Components

- DDEC engine control electronics
- ATEC transmission control electronics
- CB radio
- refrigerator in the mini-galley
- headlights

It is desirable to implement a separate 12 V system with its own alternator to power the incandescent lights used on the coach. 12 Vdc is preferred for incandescent lights for two main reasons:

- 12 Vdc filaments are more robust than 24 V filaments; and
- 12 Vdc bulbs are less expensive than the 24 V bulbs due to the higher volume usage provided by the automotive industry.

For loads up to 10 A, the 12 Vdc is delivered by tapping directly to one of the two 12 Vdc batteries used in the 24 Vdc system. This causes a load imbalance on the batteries and they require rotation to equalize battery life. For loads up to 40 A a battery equalizer is used to equalize the 12 Vdc load between the two batteries. The equalizer is required when DDEC and ATEC are used. The 12 Vdc system with separate alternator will eliminate the requirement for the equalizer.

5.4.3. 115 Vac Power Requirements

The present MCI coach has some 115 Vac requirements in addition to its dc requirements.

Present MCI 115 Vac Components

- video entertainment system;
- instation lighting.

- **Video Entertainment System** - A power inverter (24 Vdc to 115 Vac) is installed in one of the baggage compartments to provide the necessary power.

- **In-station Lighting** - In this case 115 Vac is provided by plugging the bus into an outlet in the bus station. The 115 Vac is then used to power the interior fluorescent lights and also supply lights in the baggage compartments. Two 115 Vac to 24 Vdc power converters are installed in the front junction box to supply the fluorescent lights in the parcel racks. The baggage compartments are fitted with 115 Vac bulbs as well as with 24 Vdc bulbs to allow operation from the station power or from the coach power.

5.5. Load Switching Requirements

Figures 19 to 21, along with Tables 13 to 15, indicate the various loads and how they are approximately distributed in the coach. Since MCI is currently considering adding a 12 V power system the tables show loads which can be converted to 12 V and the resulting effect on the 24 V requirements.

By examining Table 16, it is evident that if the major loads such as the condensor motor are neglected, 90% the 24 V loads can be switched with a 1.1 A switch. If 12 V is used, a 2.2 A switch is required.

Table 13 Power Requirements for the Upper Section of the Coach

Ref. No.	Item	Opt.	Qty	Device Current	Total Current for 24 V	Total Current for 12 V	Total Current for Reduced 24 V
1	RH Aisle Lights		9	1.00	9.00		9.00
2	LH Aisle Lights		10	1.00	10.00		10.00
3	RH Window Lights		6	1.10	6.60		6.60
4	LH Window Lights		7	1.10	7.70		7.70
5	RH Passenger Blower	Yes	1	8.00	8.00		8.00
6	LH Passenger Blower	Yes	1	8.00	8.00		8.00
7	RH Reading Lights		22	0.37	8.14	16.28	
8	LH Reading Lights		26	0.37	9.62	19.24	
9	Front Marker Lights		5	0.37	1.85	3.70	
10	RH Side Marker Lights		3	0.37	1.11	2.22	
11	LH Side Marker Lights		3	0.37	1.11	2.22	
12	Rear Marker Lights		5	0.37	1.85	3.70	
13	Destination Sign	Yes	1	1.00	1.00		1.00
14	Destination Sign Motor	Yes	1	1.00	1.00		1.00
15	Driver Lights		2	0.67	1.34	2.68	
16	Blinds	Yes	4	0.09	0.36		0.36
17	Step Well Light		1	0.67	0.67	1.34	
18	Lavatory Occupied Sign	Yes	3	0.37	1.11	2.22	
19	Lavatory Occupied Light	Yes	1	1.02	1.02	2.04	
20	Lavatory Night Light	Yes	1	0.30	0.30	0.60	
21	Lav Wall Occupied Sign	Yes		0.08	0.00	0.00	
22	Stop Request Sign*	Yes	3	0.24	0.72	1.44	
23	Video Monitors	Yes	6	3.00	18.00		18.00
24	VCR	Yes	1	2.00	2.00		2.00
25	5-Channel Ent. System	Yes	4	0.50	0.00	2.00	
26	Backup Camera	Yes	1	0.50	0.50		0.50
27	Blue Running Lights		3	0.37	1.11	2.22	
	TOTAL				100.50	59.68	71.66

* Can't have both stop request and lavatory occupied sign
Future coaches may have a passenger information center which will replace these features

Figure 19 Location of Loads in the Upper Section of the Coach

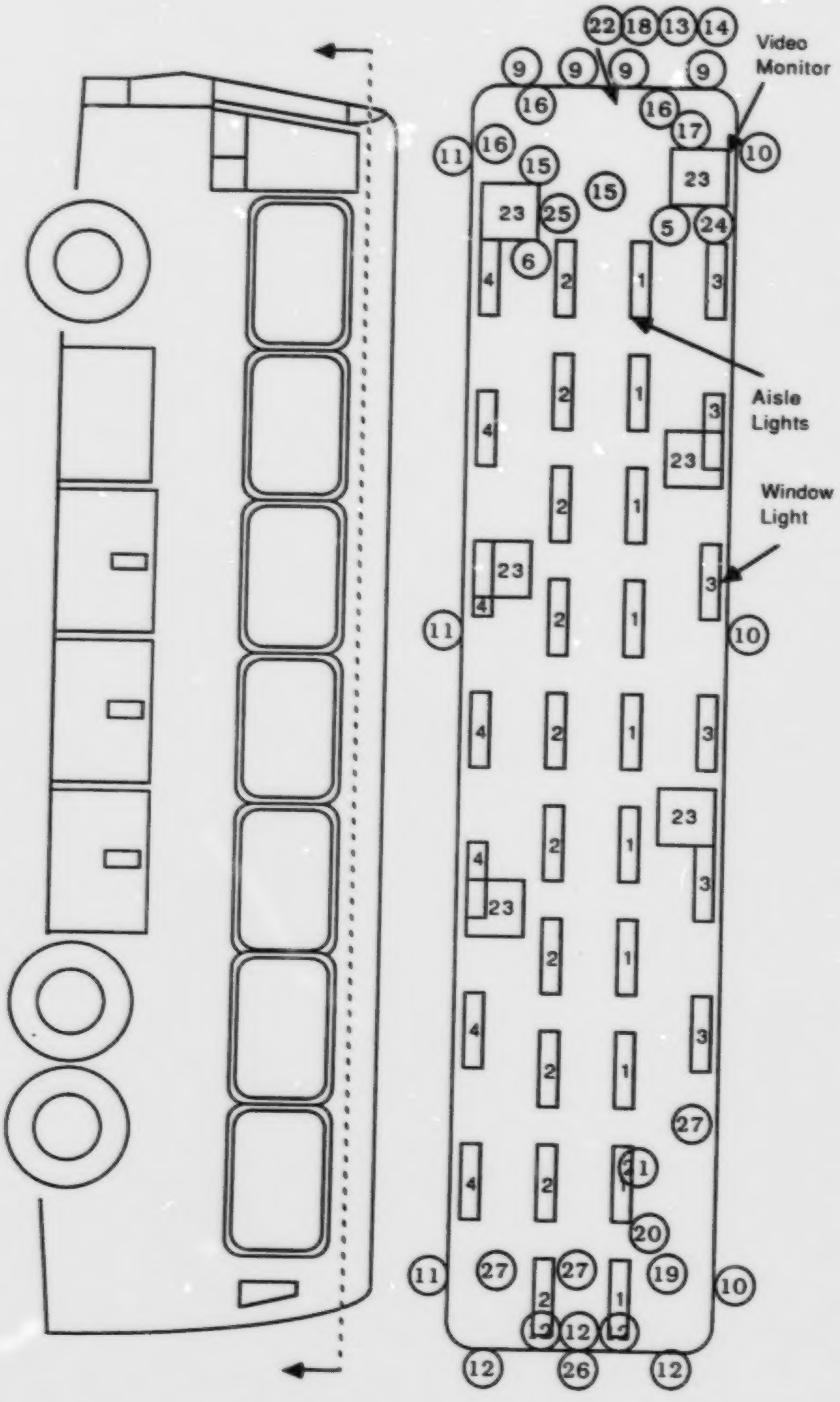


Table 14 Power Requirements for the Centre Section of the Coach

Ref. No.	Item	Opt.	Qty	Current	Total Current for 24 V	Total Current for 12 V	Total Current for Reduced 24 V
1	Step Lamps		1	0.37	0.37	0.74	0.0
2	Step Lamps		1	0.67	0.67	1.34	0.0
3	Ext Step Light	Yes	1	1.01	1.01	2.02	0.0
4	Door Latch Solenoid		1	0.40	0.40	0.40	0.0
5	Door Skinner Valve		1	0.31	0.31	0.31	0.0
6	Door Four-Way Valve		1	0.76	0.76	0.76	0.0
7	Driver's Defrost Motors		2	4.70	9.40	18.80	0.0
8	Driver's A/C Solenoid		1	0.73	0.73	0.73	0.0
9	PA Power Amp *	Yes	1	3.00	3.00	6.00	0.0
10	Underseat Aisle Lights		6	0.37	2.22	4.44	0.0
11	Buzzer		1	0.06	0.06	0.12	0.0
12	Entrance Door Chimes *	Yes	1	0.20	0.20	0.40	0.0
13	Tag Axle Sonalert	Yes	1	0.03	0.03	0.06	0.0
14	Lavatory Emerg. Buzzer	Yes	1	0.06	0.06	0.06	0.0
15	Low Coolant Buzzer	Yes	1	0.06	0.06	0.06	0.0
16	Turn Signal Clapper		1	0.11	0.11	0.11	0.0
17	Dash Lights		38	0.07	2.66	5.32	0.0
18	Tell/Tales		38	0.07	2.66	5.32	0.0
19	Radio *	Yes	1	0.50		0.50	0.0
20	Backup Monitor *	Yes	1	3.00	3.00	6.00	0.0
21	Heated Mirror (max)	Yes	2	2.50	5.00	10.00	0.0
22	Remote Adjusted Mirror *	Yes	2	0.10	0.20	0.40	0.0
	TOTAL				32.9	63.9	0.0

* Estimated
Consumptions

Figure 20 **Location of Loads in the Centre Section of the Coach**

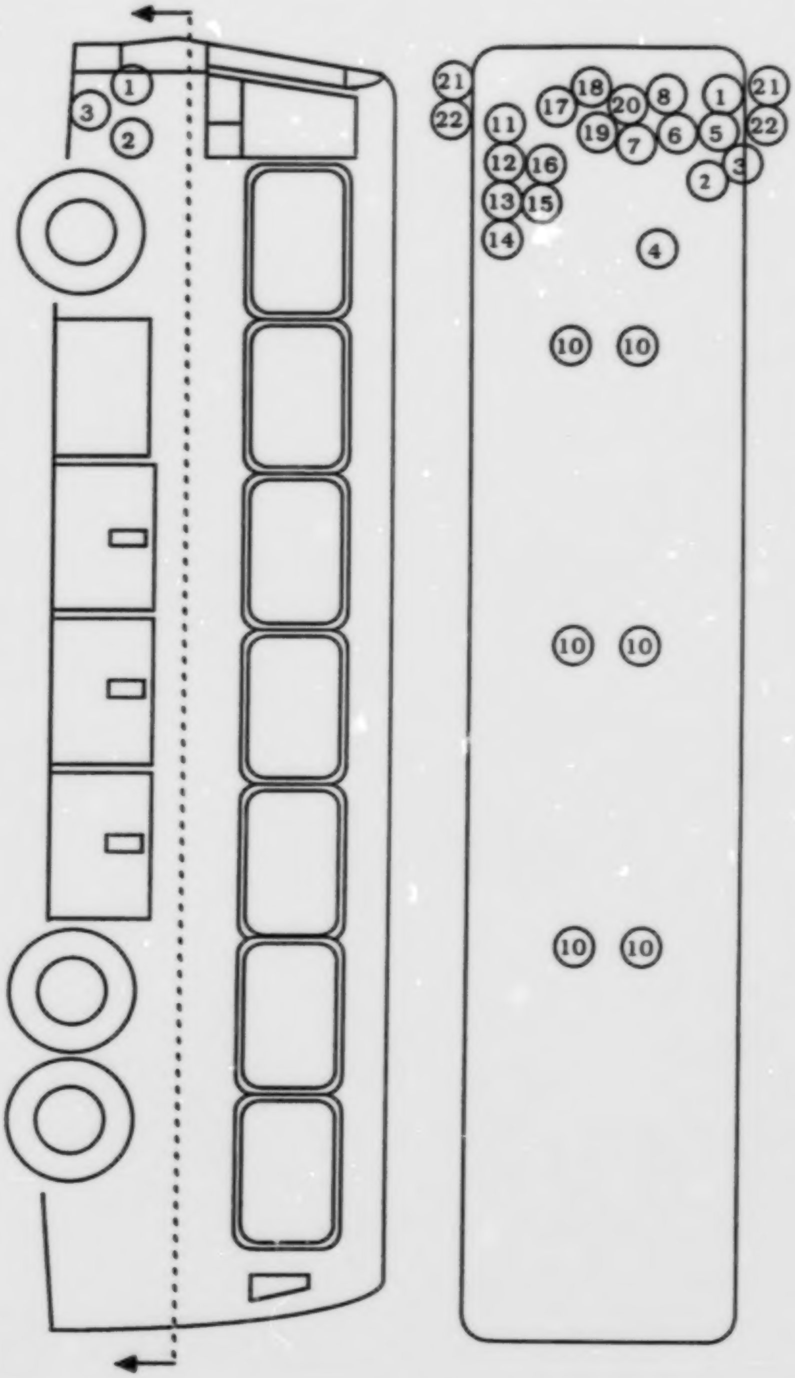


Table 15 Power Requirements for the Lower Section of the Coach

Ref. No.	Item	Opt.	Qty	Current	Total Current for 24 V	Total Current for 12 V	Total Current for Reduced 24 V
1	RH Rear Turn Signal		1	1.02	1.0	2.0	0.0
2	LH Rear Turn Signal		1	1.02	1.0	2.0	0.0
3	RH Front Turn Signal		1	1.02	1.0	2.0	0.0
4	LH Front Turn Signal		1	1.02	1.0	2.0	0.0
5	LH Baggage Comp.Lights		3	0.67	2.0	4.0	0.0
6	RH Baggage Comp.Lights		3	0.67	2.0	4.0	0.0
7	RH Headlight Lo Beam		1	3.00		3.0	0.0
8	RH Headlight Hi Beam		2	4.00		8.0	0.0
9	RH Front Marker Light		1	0.37	0.4	0.8	0.0
10	LH Headlight Lo Beam		1	3.00		3.0	0.0
11	LH Headlight Hi Beam		2	4.00		8.0	0.0
12	LH Front Marker Light		1	0.37	0.4	0.8	0.0
13	RH Rear Backup Light		1	1.02	1.0	2.00	0.0
14	RH Rear Tail Light		1	0.37	0.4	0.80	0.0
15	RH Rear Brake Light		1	1.02	1.0	2.00	0.0
16	LH Rear Backup Light		1	1.02	1.0	2.00	0.0
17	LH Rear Tail Light		1	0.37	0.4	0.80	0.0
18	LH Rear Brake Light		1	1.02	1.0	2.00	0.0
19	License Plate Lamp		1	0.37	0.4	0.80	0.0
20	Rear J Box Light		1	0.67	0.7	1.40	0.0
21	Air Dryer		1	5.00	5.0		5.0
22	Docking Lights	Yes	6	3.00	18.0	36.00	0.0
23	Additional Side Turn Signals	Yes	2	1.02	2.0	4.00	0.0
24	Additional Front Turn Signals	Yes	2	1.02	2.0	4.00	0.0
25	A/C Liquid Line Solenoid		1	0.73	0.7	0.70	0.0
26	Coach Heat Valve		1	0.32	0.3	0.30	0.0
27	Wheel Chair Solenoids *		4	0.40	1.6	1.60	0.0
28	Wheel Chair Alarm *		1	0.10	0.1	0.10	0.0
	Sub Total				**44.4**	**98.1**	**5.0**
29	Condensor Motor		1	45.00	45.0		45.0
30	Evaporator Motor		1	48.00	48.0		48.0
	Total				**137.4**	**98.1**	**98.0**
31	Wheel Chair **	Yes	1	100.00	100.00		100.0
32	Starter Motor		1	382.00	382.0		382.0

* Estimated Consumption
** This is for the Stewart and Stevenson Wheelchair Ramp only.

Figure 21 Location of Loads in the Lower Section of the Coach

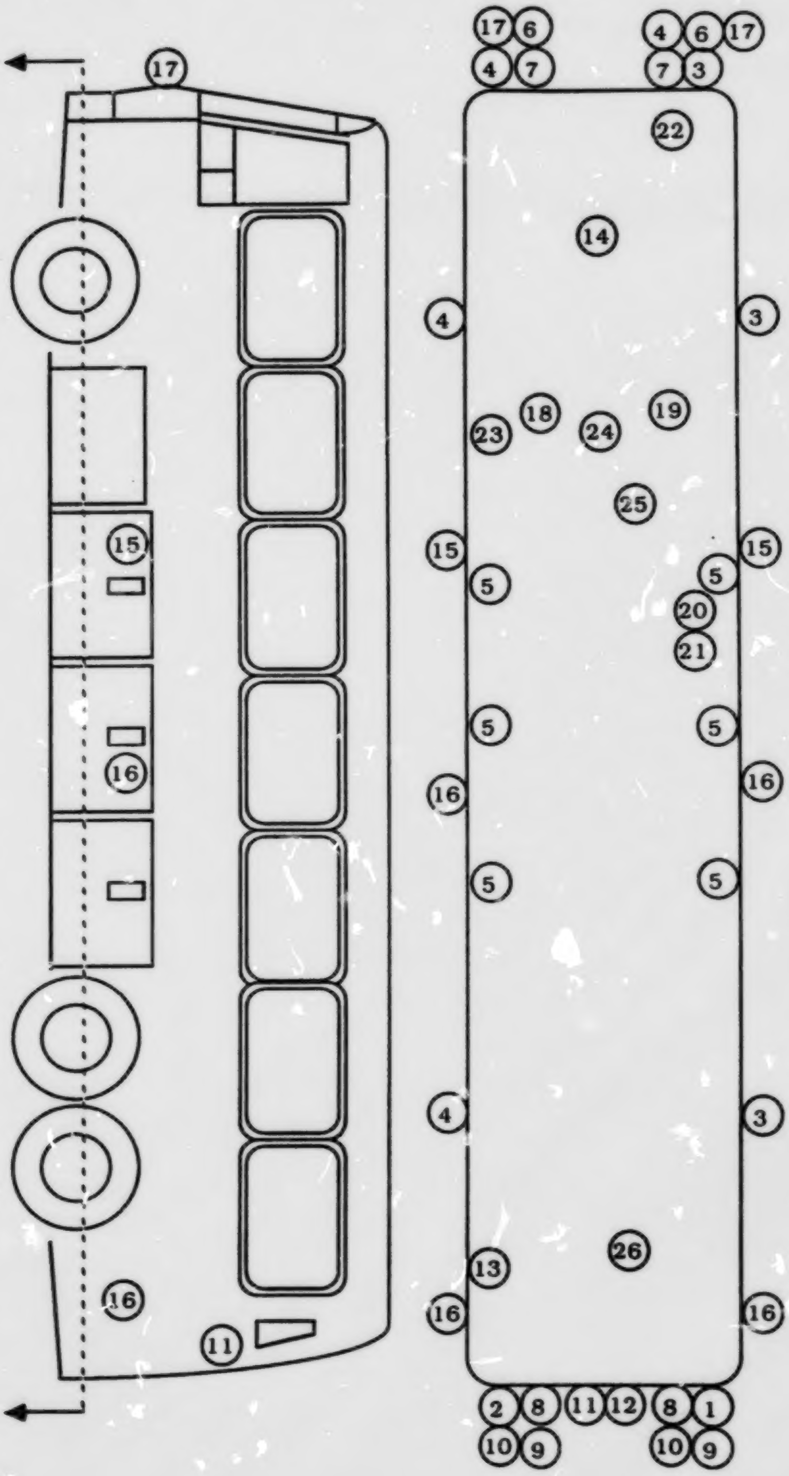


Table 16 Selection Criteria for Power Switch Ratings

Switch Current	% of Loads Switched
24 V:	
1.0 A	75 % of 193 loads
1.1 A	90 %
2 A	90 %
5 A	98 %
Potential 12 V:	
1 A	72 % of 118 loads
2 A	81 %
2.2 A	95 %
5 A	95 %
10 A	100 %

Note: Loads greater than 12.5 A are neglected.
Potential 12 V loads only include incandescent lights.

5.6. Sensor and Sensor Switch Requirements

The current sensors and sensor switches are tabulated in Table 17 and shown in Figure 22. Most of the sensors are concentrated in the vicinity of the engine compartment. Table 18 summarizes the current sensors. The future sensor requirements can be obtained by examining Tables 11 and 12.

In the future many of the switch closure type sensors will be replaced by sensors providing the raw signal. This will provide better diagnostic information. The switching functions will be performed by a controller on the bus detecting a signal beyond its limits.

Table 17 Coach Sensors & Sensor Switches

Ref. No.	Item	Opt.	Qty	Function
1	Entrance Door Switch		1	Enables step lights and chimes when door is open. Enables door latch solenoid when door is closed.
2	RH Baggage Comp. Micro Sw.		3	Activates associated compartment light.
3	LH Baggage Comp. Micro Sw.		3	Activates associated compartment light.
4	Reverse Switch		1	Used for backup lights & rev. throttle interlock.
5	Neutral Switch		1	Used for engine starting.
6	Freon High Pressure Sw.		1	Detects high pressure in AC system.
7	Freon Low Pressure Sw.		1	Detects leaks in AC system.
8	Parking Brake Pressure Sw.		2	Indicates parking brake is applied.
9	Service Brake Pressure Sw.		1	Indicates service brake is applied.
10	Low Oil Pressure Sw.		1	Used to shut engine down if oil pressure is too low.
11	Alarmstats		2	Signals hot engine
12	Water Temp. Sender		1	Drives water temperature gauge.
13	Oil Pressure Sender		1	Drives oil pressure gauge.
14	Magnetic Pickup		1	Drives speedometer.
15	Thermocouple Pickup		1	Part of HVAC
16	Fuel Level Sender	Yes	1	Drives fuel level gauge
17	Low Fuel Sensor	Yes	1	Drives low fuel warning T/T
18	Transmission Temp. Sender	Yes	1	Drives transmission temperature gauge
19	Fuel Pressure Switch	Yes	1	Part of thermal time delay circuit
20	Transmission Switch	Yes	1	Part of two speed governor circuit.
21	Trans. Rev. Press. Switch	Yes	1	Part of reverse throttle interlock
22	Fast Idle Buffer Switch	Yes	1	Part of Jacob's brake circuit
23	Fire Alarm Detectors	Yes	2	Part of fire alarm circuit
24	Low Coolant Sensor	Yes	2	Detects low coolant level in surge tank
25	Water Level Detector	Yes	1	Detects low coolant level in fill tank (optional).
26	Thermostat	Yes	1	Used in either start system.
27	Magnetic Probe	Yes	1	Used in cruise control to sense vehicle speed.
28	Tag Axle Pressure SW	Yes	2	Used to indicate low air pressure in tag axle.
29	Clutch Microswitch	Yes	1	Needed for Jacob's brake and cruise control
30	Pressure Switch	Yes	1	Part of Kneeling Feature
31	Retractable Step	Yes	1	Detects Retractable Step Location
32	Alternator A1 Output	Yes	1	Needed to drive tachometer
	Subtotal		**41**	
33	Wheel Chair Sensor/Sw.	Yes	22	Used on Wheel Chair Ramp
	Total		**63**	

Figure 22 Coach Sensors & Sensor Switches

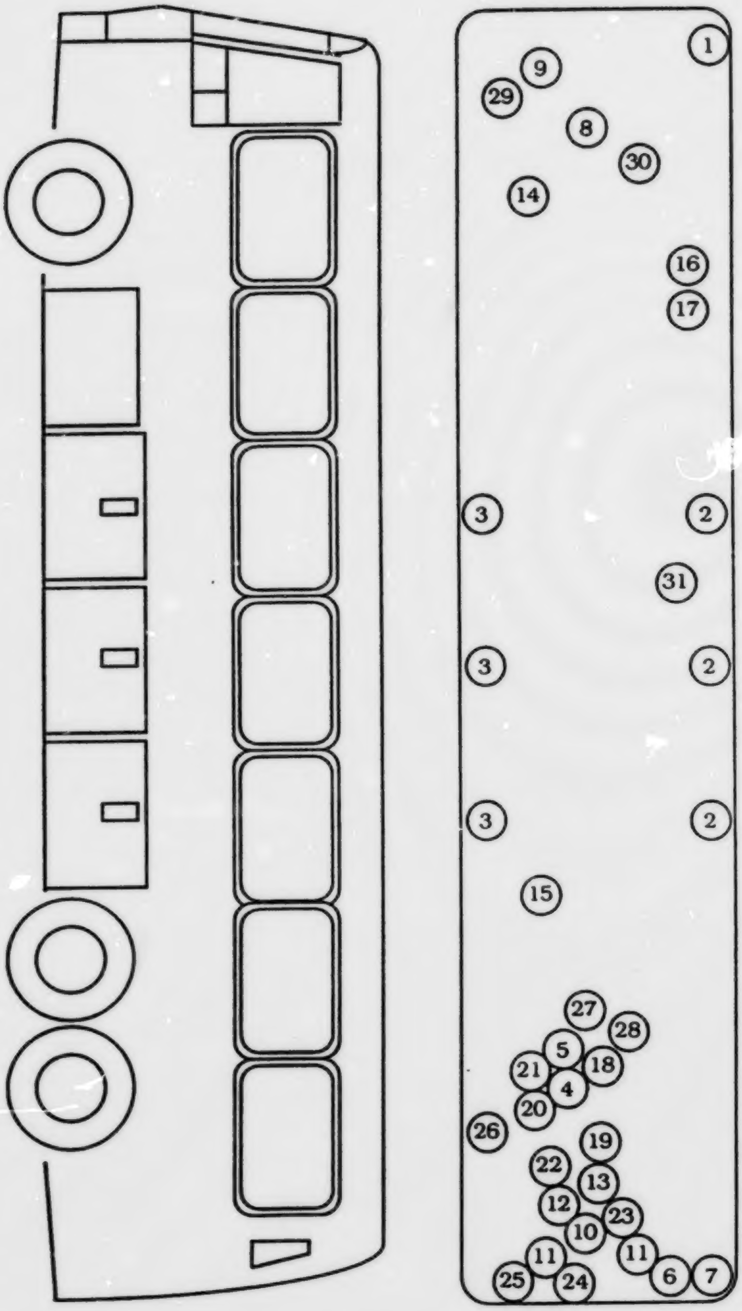


Table 18 Coach Sensor Summary

Sensor Type	Quantity
Variable Resistance	4
Thermocouple	1
Pulse Train	2
Switch Closures	54

6. SYSTEM DESIGN

6.1. Example Multiplexed System Design for the MCI 102C3 Coach

Figure 23 is a block diagram of a sample multiplex system for the MCI 102C3 coach. It consists of a Class B bus with several Class B nodes controlling Class A networks. No Class C multiplexing is used although a Class C backbone and Class C nodes could easily replace the Class B network. There is currently no need for Class C data, but it is expected that a J1922 link will connect the anti-lock braking system, transmission, engine and throttle in the near future.

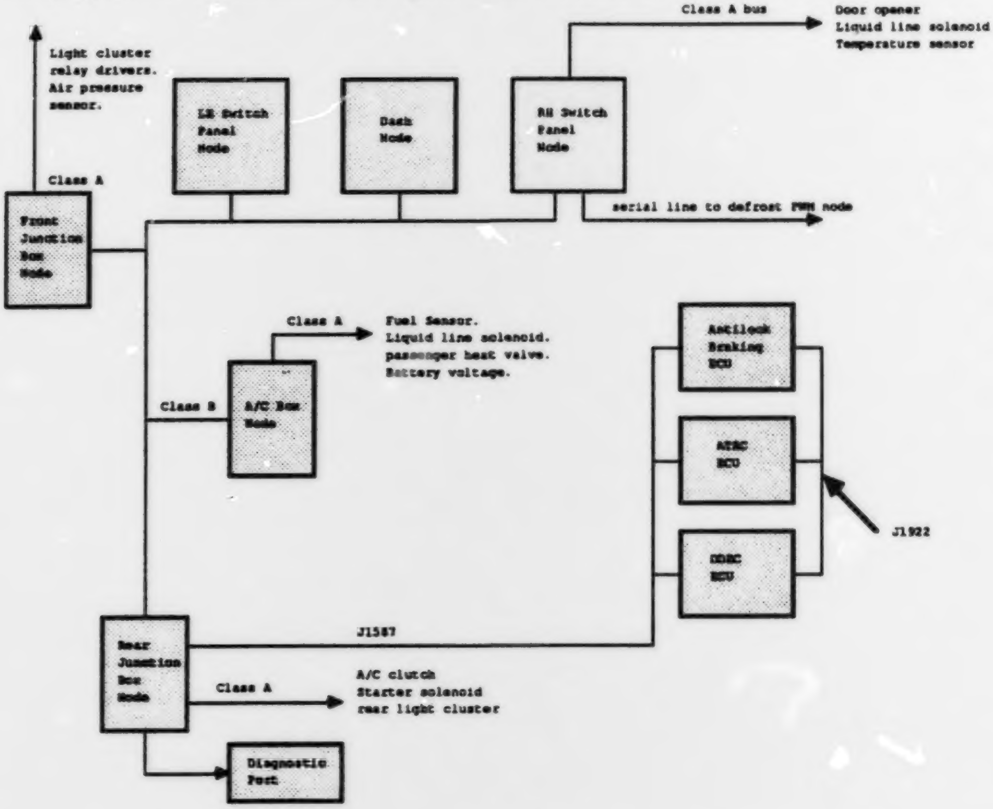


Figure 23 Sample Multiplex System

The driver's interface can consist of an LCD display used in the trucking industry (Figure 24) and one or two graphic touchscreen displays (Figure 25). The touchscreen displays replace the switch panels and provide tell-tale information.

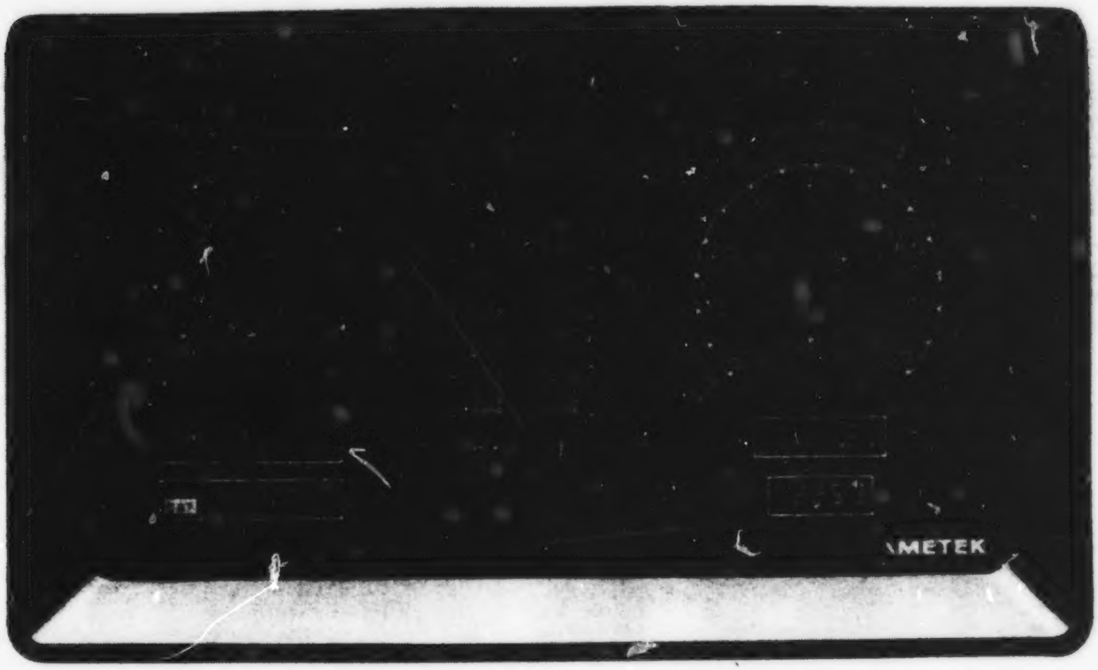


Figure 24 Multiplex LCD Truck Dash Display Currently in Use

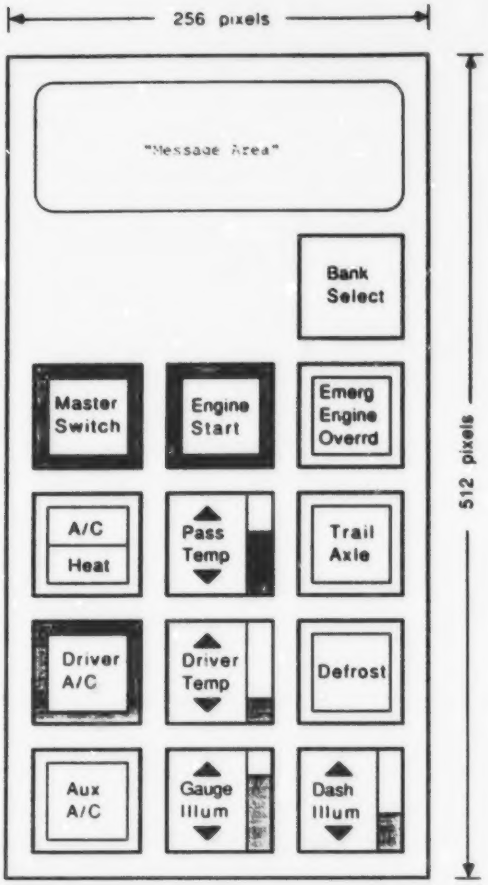


Figure 25 One Possible LCD Touchscreen Display. Feedback to the driver of switch function can be provided by shading the outline of a switch, or by changing the output of a bar graph beside the switch.

6.1.1. Class B Node Functions

6.1.1.1. Rear Junction Box

The node in the rear junction box will be responsible for starting and shutting down the engine and monitoring data from the various sensors. It will provide a global signal to indicate if the charging system is functional and if the air pressure is adequate. All data will be transmitted to the nodes in the front of the coach and a large part of the main harness is eliminated. The triple function protection device is eliminated as well as a number of relays used in starting and controlling the engine. The node also controls Class A power switches located on the rear tail light clusters.

6.1.1.2. Junction Box

The node in A/C junction box will be responsible for input data from the fuel level sensors and controlling the motors and valves for the HVAC system. The HVAC controller will no longer be required. The switch panels will be used for providing the driver's interface to the HVAC system. Side turn signal lamps will also have to be switched by the A/C junction box node.

6.1.1.3. Front Junction Box

The node in the front junction box will input data from the turn signal actuator and data from the switch panels. It will switch the necessary relays in the junction box as dictated by the switch panels. The present flasher circuit will be eliminated and there is potential for the node to also generate the audio feedback for the driver.

6.1.1.4. RH Switch Panel Node

This node will service the RH switch panel and also control the door opening hardware using a Class A bus.

6.1.2. Class A Node Functions

Class A multiplexing can be used more extensively in the design but the example system uses Class A systems with the maximum potential economic benefits. Class A multiplexing will become more economically attractive as soon as smart switches become more prevalent in the marketplace.

A potential initial design can avoid Class A multiplexing altogether and just use the Class B nodes to handle the signals already present in the junction boxes. The advantage with this approach is that most of the harnesses connecting to the devices remain intact. Since the environment inside the junction boxes is not as severe as at the device connections, constraints on packaging and device selection are reduced substantially. With this approach the main harness, harnesses connecting to the dash, special controllers and several relays are eliminated where a large portion of the cost exists.

6.1.3. Multiplexing Potential for Class A

Figures 19 to 21 reveal how the power consuming devices are distributed throughout the coach. The major power consumers are the motors in the air conditioning system, the fluorescent lights and reading lights in the parcel racks, and the headlights.

A larger percentage of the low power nodes have current draws between 0.5 - 1 A. This means that for individually wired subsystems a multiplexed system using 14 AWG branch circuits can reduce, at best, 15 - 30 wires to one wire. However, circuits often have multiple loads and the advantage is drastically reduced. Table 19 shows several circuits where there is not much gain to be realized with Class A multiplexing since the wiring for these circuits is already well utilized in delivering the power to the load.

Table 19 Circuits Having Multiple Loads

Circuit Description	Total Load
Aisle Lights	19 A/24 V
Window Lights	14.3 A/24 V
Reading Lights	17.8 A/24 V or 35.6 A/12 V
ID & Clearance Lamps (roof)	6 A/24 V or 12 A/12 V

Circuits which will benefit the most from Class A multiplexing are those operating single low power loads, especially where the loads are close together and where long wire segments are required. An example of such a circuit is the rear tail light cluster.

6.2. Choice of Systems to Implement with Multiplexing

6.2.1. Roof and Parcel Racks

No multiplexing has been used in the roof and parcel rack systems. This is due to the fact that these systems are very power-intensive and large numbers of devices typically operate from the same signal. The most likely candidates for future design are:

- **Stop Request System** - a latching relay can be eliminated by using software in an existing node;
- **Passenger Information Centre** - this would display many items of passenger interest such as external temperature, time, lavatory occupied, etc. A display similar to the electronic destination sign can be used or a rotating LED sign;
- **Electronic Destination Sign**;
- **Driver and Step Well Ceiling Lights**;
- **Lavatory Occupied Light**.

The electronic destination sign and the passenger information centre will be easily handled with the multiplexing system. No additional programming modules are required since the dash and driver switch panel can be used.

6.2.2. Video and Audio Systems

Video and audio signals consume a very large bandwidth and are not included in multiplexing system. It would be possible to do an audio/video multiplexing system on fibre optic cable for an entertainment system with several different user selectable programs, although the cost of this type of system is probably too high to compete with existing systems.

6.2.3. DDEC, ATEC, and Anti-Lock Braking/Traction Control

These systems will eventually be connected by a J1922 link. The anti-lock braking system may eventually become distributed in nature with Class C nodes located at each wheel.

6.3. Dash Design

The main considerations for the dash are:

- provide necessary feedback of vehicle operation to the driver;
- prevent information overload to the driver;
- provide transparent expansion/reduction;
- provide intuitive operation.

6.3.1. Transparent Expansion/Reduction

The key element necessary to provide the transparent/expansion reduction for the system is the graphic display touchscreen (see Figure 25). The screen has infra-red beams scanning its face to detect when the driver's finger approaches. Different switches can easily be added or removed as dictated by the controlling node, since they are only software-generated graphic images. Tell-tale information can be displayed in a special area of the screen and an alarm can be sounded if necessary. In this way the dash can easily accommodate new subsystems.

Some functions are less important such as programming of the destination sign. These features can be selected by entering a background menu. When programming is being performed, the entire screen can be used. It is also possible to have the whole screen display a route map, if a navigation system is present. A touch of the finger can return the display to the normal switch panel. With some additional hardware, it is possible to display the image from the backup camera on the same screen as well. Alternatively, it is possible to construct a graphical image representing the feedback from an ultrasonic backup system.

A cheaper alternative to the touchscreen would be to have push button switches located on the sides of the display to implement "soft keys". The function of the switch would correspond the label beside it.

6.3.2. "Information Overload"

With multiplexing, it is easy to provide much more information to the driver than he can handle. It is important not to cause information overload. Information overload can be prevented using a form of data filter in the dash controller node. This system acts as a copilot and examines all the incoming information and provides the driver only the information worthy of his attention.

In its simplest form the data filter is implemented by comparing the incoming data against predetermined thresholds. If the data traverses the thresholds, routines are executed which display tell-tale and diagnostic information or generate special sounds. A prioritized arbitrator is required to handle the situation where multiple faults occur simultaneously.

A more intelligent, and complex, form of the data filter can be an expert system which advises the operator on what course of action to take. This can be done by examining rates of change of critical data and the data available from other sensors simultaneously.

6.3.3. Design Details

6.3.3.1. Replacing the Switch Panels

Table 20 shows the various switches in the existing switch panels and the approximate loads on each. Loads which are difficult to implement with solid-state switches are:

- readings lights;
- mirror heat (high current heaters only).

Both these are optional equipment. Some loads in Table 20 are controlled by the multiplexing system already. The driver's defrost motor is assumed to be controlled by a PWM module. This leaves 13 relays which have to be driven in the front junction box using solid state switches.

In the long term, the relays will be replaced by Class A power switches at the loads. Junction box requirements will be significantly reduced.

Table 20 Existing Switch Panel Loads

LH Upper Switch Panel (Left to Right):

Switches	Current (A)	Function
Engine Start Switch	0.1	Starting
	0.4	Override
Master Control Switch	0.3	
Emergency Engine Override Switch	0.4	
Mirror Heat Switch	6	
Blank		
Passenger Ventilation Switch	0.06	
Driver A/C Switch	0.12	
Trail Axle Switch	0.51	
Fast Idle Switch	0.4	
Reading Lights Switch	18	
Passenger A/C-Heat Switch	0.44	A/C
	0.38	Heat
Drivers Defrost		Low
		Medium
	18.8	High

LH Lower Switch Panel (left to right):

Switches	Current	Function
Cruise Control On/Off Switch	1	
Blank		
Cruise Control Set/Res Switch	0.1	
Dash Illumination Rheostat	1.755	
Bulb Test Switch	0.845	0 V output
	1.625	24 V output
Gauge Illumination Rheostat	0.65	

RH Switch Panel (left to right):

Switches	Current	Function
Steplight and Chimes Switch	1.82	
Step Out Switch	0.06	Out
	0	Off
	0	In
Entrance Door Switch	0.12	Open
	0.31	Hold
	0	Close
Blank		
Blank		
Drivers Light	0.71	
Clearance and ID Lights Switch	0.3	
Headlight Switch	0.9	
Hazard Switch	8.27	
Coach Lights Switch	0.46	Aisle
	0.92	All
Jacobs Brake Switch	5.73	
Blank		

The least expensive graphic display to use for the switch panels is LCD. Backlighting can be used to supply heat for cold weather operation. LCD displays are desirable because they are the lowest cost and are light-reflecting rather than light-emitting giving them an advantage over gas plasma and vacuum fluorescent displays when operating in bright sunlight. The touchscreen can be added on top of the display regardless of the technology used for the display.

6.3.4. Future Considerations

The driver interface of vehicles will take on different forms in the future. Graphic displays will definitely have their place, and there will be more use of Head Up Displays (HUDs) which have been used in fighter aircraft using the MIL-STD-1553 multiplexed systems. Multiplexing makes this easy to implement when the time arises. Futaba Corporation has already developed a small HUD for the automotive industry.

One possibility to implement the driver switches is to have a pressure sensitive (or other technology) touch pad on the rear of a steering wheel column where the hand would normally sit. A corresponding switch panel can be shown on a HUD with the position of the driver's finger shown where it currently is. Increased pressure can be used to make the selection. All this can be done without the driver taking his eyes off the road.

6.4. Node Design

The design of the nodes will vary with the level of the technology. The first item that must be addressed is component availability.

6.4.1. Component Availability

6.4.1.1. Microprocessors

Table 21 shows a representative set of microprocessors and pricing information. From this set it appears that the Texas Instruments TMS370 series offers the best price/performance ratio. Key features provided by a typical TMS370 processor are:

- interface to standard EPROM, Flash, and EEPROM memory without glue logic;
- on-board EEPROM for programming of address and storage of diagnostic information;
- on-board A/D converters;
- on-board watchdog timers;
- on-board pulse width modulators.

Table 21 Representative Microprocessor Specifications

Company	Part Number	eeprom bytes	ram bytes	A/D	PWM	watch-dog	Interface w/o Glue	SPI	SCI	powerfail detect	PRICE (100's)
T.I.	TMS370C050FNA	256	256	8 bit	•	•	•	•	•		$8.24
T.I.	TMS370C050FNA	256	256	8 bit	•	•	•	•	•		$9.19
T.I.	TMS370C150FNA	0	256	8 bit	•	•	•	•	•		$6.77
T.I.	TMS370C156FNA	0	512	8 bit	•	•	•	•	•		$8.06
T.I.	TMS370C250FNA	256	256	8 bit	•	•	•	•	•		$7.66
T.I.	TMS370C256FNA	512	512	8 bit	•	•	•	•	•		$10.51
Intel	P80C31BH	0	128						•		$3.85
Intel	P80C51FA	0	256		•	•			•		$8.55
Intel	P8031AH	0	128						•		$2.45
Intel	P80C152JC	0	256						•		$16.00
Motorola	MC68HC05B6	256	176	8 bit	•	•			•		$10.48
Motorola	MC68HC05B4	0	176	8 bit	•	•			•		$8.02
Motorola	MC68HC705C8	0	176		•	•		•	•		$6.15
Motorola	MC68HC05A6	2096	176		•			•	•		$9.00
Motorola	MC68HC11A1FN	512	256	8 bit	•	•		•	•		$12.9[illegible]
Motorola	MC68HC11A0FN	0	256	8 bit	•	•		•	•		$10.90
Motorola	MC68HC11E1FN	512	512	8 bit	•	•		•	•		$15.42
Motorola	MC68HC11F1FN	512	1024	8 bit	•	•	•	•	•		$17.25
Hitachi	HD6473308CP10	0	512	8 bit	•	•	•		•		$19.40
Hitachi	HD6473308CG10	0	512	8 bit	•	•	•		•		$146.15
Hitachi	HD6473308F8	0	512	8 bit	•	•	•		•		$18.45
Hitachi	HD6433308CP6	0	512	8 bit	•	•	•		•		$17.45
Hitachi	HD6433308F6	0	512	8 bit	•	•	•		•		$17.45
Hitachi	HD6475328CP6	0	1024	10 bit	•	•	•		•		$24.90
Hitachi	HD6475328CG10	0	1024	10 bit	•	•	•		•		$12[illegible].20
Hitachi	HD6475328F8	0	1024	10 bit	•	•	•		•		$25.70
Hitachi	HD6435328CP6	0	1024	10 bit	•	•	•		•		$18.80
Hitachi	HD6435328F6	0	1024	10 bit	•	•	•		•		$17.90

6.4.1.2. Memory

Table 22 shows various types of memory available and representative pricing. From this table it is apparent that EPROM is much cheaper than Flash memory. Additional points to mention include:

- high density memory is almost as cheap as low density;
- EPROM can be written in parts so that new versions of software can be loaded anywhere into available memory;
- the writing time for all of these technologies is roughly identical; and
- external hardware to provide the on-board programming for the EPROM is relatively inexpensive.

Table 22 Representative Memory Specifications

Type	Company	Part Number	Size	Price (100s)	Screening
OTP ROM	Intel	P27C256-200V10	32K	$2.70	commercial
	Texas Instruments	TMS27PC512-2NE	64K	$6.26	extended
	Texas Instruments	TMS27PC512-2NL	64K	$5.01	commercial
	Texas Instruments	TMS27PC256-2NE	32K	$4.09	extended
	National Semiconductor	NMC27C512ANE200	64K	$7.95	extended
	National Semiconductor	NMC27C256BNE200	32K	$5.15	extended
EPROM	Intel	D87C257-250V05	32K	$5.00	extended
	Intel	D87C64	8K	$3.90	extended
	Intel	TD27512-150V10	64K	$6.30	extended
	Intel	TD27C256-200V10	32K	$4.30	extended
	Intel	TD27C128A-20	16K	$4.05	extended
	Intel	TD27C64-20	8K	$3.60	extended
	Texas Instruments	TMS27C512JE	64K	$6.68	extended
	Texas Instruments	TMS27C256-2JE	32K	$4.51	extended
	Texas Instruments	TMS27C128JE	16K	$4.68	extended
	National Semiconductor	NMC27C010QE250	128K	$12.20	extended
	National Semiconductor	NMC27C512AVE250	64K	$9.30	extended
	National Semiconductor	NMC27C256BQE200	32K	$5.95	extended
	National Semiconductor	NMC27C128BQE200	16K	$5.45	extended
EEPROM	National Semiconductor	NMC9306EN	256 bit	$1.22	extended
	National Semiconductor	NMC9306EN/A+	256 bit	$1.54	burn-in
	National Semiconductor	NMC9306MN	256 bit	$4.65	military
	National Semiconductor	NMC9346EN	1024 bit	$1.50	extended
	National Semiconductor	NMC9346EN/A+	1024 bit	$1.82	burn-in
FLASH	Intel	TN28F010-200P1C4	128K	$34.00	extended
	Intel	TN28F512-200P1C4	64K	$19.10	extended
	Intel	TN28F256-170P1C2	32K	$13.10	extended

6.4.1.3. Smart Power Components

Self-Protecting Smart Power Devices

(Currents range from 1 A to 12 A, prices from $2 - $6 in quantities of one thousand. These are 5-lead, high side drivers.)

These devices are restricted to 60 V peak voltage and as such are not currently compatible with the coach transient protection requirements.

LM1951	National Semiconductor
LT1188	Linear Technology
SP306	Harris Semiconductor
HA13702A	Hitachi
HA13703A	Hitachi
BTS-412A	Siemens
BTS-432	Siemens
MPS1510	Motorola

Smart Gate Drivers

These devices identical except for the voltage ratings (500 V for the IR2110, and 600 V for the SP606). These are half-bridge drivers for use in power-conversion and motor-control applications. Outputs from these devices include both high-side and low-side channels, rated at 2 A. Other features include Schmitt-triggered inputs with hysteresis and pull-down, cycle-by-cycle edge-triggered shutdown logic, and undervoltage lockout with hysteresis for both channels.

IR2110	International Rectifier	(costs $7 in thousands)
SP606	Harris Semiconductor	(costs $7 in thousands)

Smart Predrivers

For driving N-channel power MOSFETs. Contain an integral voltage pump for gate drive greater than Vdd in both high and low side drive applications. Contain a programmable over-current sensing shutoff comparator. Protection includes fault detection and power on reset, and thermal shutdown.

MIC5010	Micrel	(costs $2.25 in hundreds)
MIC5011	Micrel	(costs $1.95 in hundreds)

Smart Drivers

(low-side drivers suitable for driving automotive incandescent lamps)

- **UDN2547 (Sprague)** - Quad driver, 40 V @ 600ma each. Output current limiting, and thermal shutdown. Costs $2.09 in thousands.

- **TPIC2404 (Texas Instruments)** - Quad driver, 45 V @ 1 A each. Independent thermal shutdown, overvoltage shutdown, and current limiting. Also includes output clamp diodes for protection against transients when switching inductive loads. Costs $4.83 in thousands
- **TPIC2406 (Texas Instruments)** - Quad driver, 60 V @ 3 A pulsed. Independent channel protection, fault sensing and reporting, thermal shutdown. Outputs can be paralleled to provide 12 A pulsed. Costs $2.80 in thousands.
- **MIC4807 (Micrel)** - 8-channel driver, 80 V @ 100ma each. Output current limiting, thermal shutdown. Also has PWM input which is useful in controlling brightness of incandescent lamps. Costs $3.95 in thousands.
- **L6280 (SGS-Thomson)** - 3-channel driver. Integrates two 1 A motor drivers, a 3 A solenoid driver, a 5 V @ 1 A switching power supply, and a microprocessor interface. The chip can be directly connected to a microprocessor bus. Commands loaded into internal registers control the device's power-driving circuits. Thus current control is performed by software. The device features protection against potentially damaging software errors, powerfail protection, thermal shutdown, current limiting, and a watchdog controller. Cost is $9 in thousands.

Smart Semicustom Devices

- **6000 Series (Cherry Semiconductor)** - Integrates two power transistors, rated at 50 V @ 2.5 A each, and one of 12 linear or linear/digital chips in the company's family of semicustom circuits. For example, choosing the 1500 linear/digital array will allow 98 logic gates, 198 linear transistors, and 462 resistors with which to design the "smart" portion of the circuit. Choosing the 5000 linear-only array will allow the implementation of signal processing and power capabilities that require as many as 314 transistors and 858 resistors. On-chip protection features such as overvoltage and undervoltage shutdown, current limiting, and thermal shutdown are easily implemented using uncommitted semi-custom arrays. Typical cost is $3 in thousands.

6.4.1.4. Class B and Class C Multiplexed Bus Interface

Several ICs are currently available to perform the bus interface. GM is about to sample J1850 interface ICs. The approximate cost of these devices will be $4.00.

The devices include the transceiver components. CAN chips are available from Intel and cost $22.00 in 100s. These chips do not include bus transceivers.

6.4.1.5. Class A Multiplexed Bus Interface Components

Components supporting CSC multiplexing are available. These include the following:

- A hall effect input sensor. This sensor is available from Sprague and costs approximately $1.00. The sensor can also be used to connect a switch to the CSC bus.
- A quad relay driver is available from EXAR and costs approximately $1.50.
- A bus interface IC is available from Cherry Semiconductor and costs approximately $0.40.

6.4.1.6. Smart Motors

There are no motors which can directly connect to a multiplexed bus. What companies are marketing as smart motors are merely motors which can be used with external electronics to form a smart motor. This is expected to change in the near future.

6.4.1.7. Power Transistors

Potential transistors to use for load switching are shown in Table 23 along with representative pricing and other information.

Table 23 Representative Transistor Specifications

Part No.	VDSS	rDS(on)	Package	Price	Current for 1 W Dissipation	Current for 3 W Dissipation
N Channel:						
MTP8 10 E	100	0.5	TO-220	$0.75	1.41	2.45
MTP10 N10E	100	0.25	TO-220	$0.81	2.00	3.46
MTP10N10M	100	0.25	314B SENSEFET	$1.65	2.00	3.46
MTP20N10E	100	0.15	TO-220	$1.94	2.58	4.47
IRF631	150	0.4	TO-220	$1.36	1.58	2.74
MTP10N15	150	0.3	TO-220	$1.43	1.83	3.16
IRF643	150	0.22	TO-220	$3.00	2.13	3.69
IRF641	150	0.18	TO-220	$3.32	2.36	4.08
MTM20N15	150	0.12	TO-204 (TO-3)	$3.77	2.89	5.00
IFR612	200	2.4	TO-220	$0.43	0.65	1.12
MTP2N20	200	1.8	TO-220	$0.53	0.75	1.29
MTP5N20	200	1	TO-220	$0.86	1.00	1.73
IRF620	200	0.8	TO-220	$0.90	1.12	1.94
MTP8N20	200	0.4	TO-220	$1.43	1.58	2.74
MTH15N20	200	0.16	TO-220	$3.77	2.50	4.33
MTP4N25M	250	1.5	314B SENSEFET		0.82	1.41
MTP10N25	250	0.45	TO-220	$2.86	1.49	2.58
MTP10N25M	250	0.45	314B SENSEFET		1.49	2.58
MTH30N25	250	0.14	TO-218	$8.80	2.67	4.63
MTH30N25E	250	0.14	TO-218	$10.12	2.67	4.63
IRF731	350	1	TO-220	$1.26	1.00	1.73
IRF741	350	0.55	TO-220	$3.14	1.35	2.34
MTH15N35	350	0.3	TO-204 (TO-3)	$6.86	1.83	3.16
MTD1N40	400	5	DPAK SMT	$0.73	0.45	0.77
MTP3N40	400	3.3	TO-220	$0.76	0.55	0.95
MTP3N40E	400	1	TO-220	$1.41	1.00	1.73
MTP10N40E	400	0.55	TO-220	$1.82	1.35	2.34
MTP3N50E	500	3	TO-220	$0.99	0.58	1.00
P Channel:						
MTP8P10	100	0.4	TO-220	$2.90	1.58	2.74
MTP12P10	100	0.3	TO-220	$3.00	1.83	3.16
MTH20P10	100	0.15	TO-218	$7.15	2.58	4.47
MTP5P18	180	1	TO-220	$2.75	1.00	1.73
MTH8P18	180	0.7	TO-218	$4.10	1.20	2.07
MTP8P25	250	2	TO-220	$4.50	0.71	1.22

6.4.2. Class A Node Design

Class A node designs are primarily required for the switches. Various numbers of switches can be combined in one module to reduce the overhead imposed by the interface. However, more switches in the nodes complicates the harness requirements for connecting the switch to the loads. Interface chips are currently designed for controlling four switches. Figures 26 and 27 are possible implementations of a Class A node based on a quad power device.

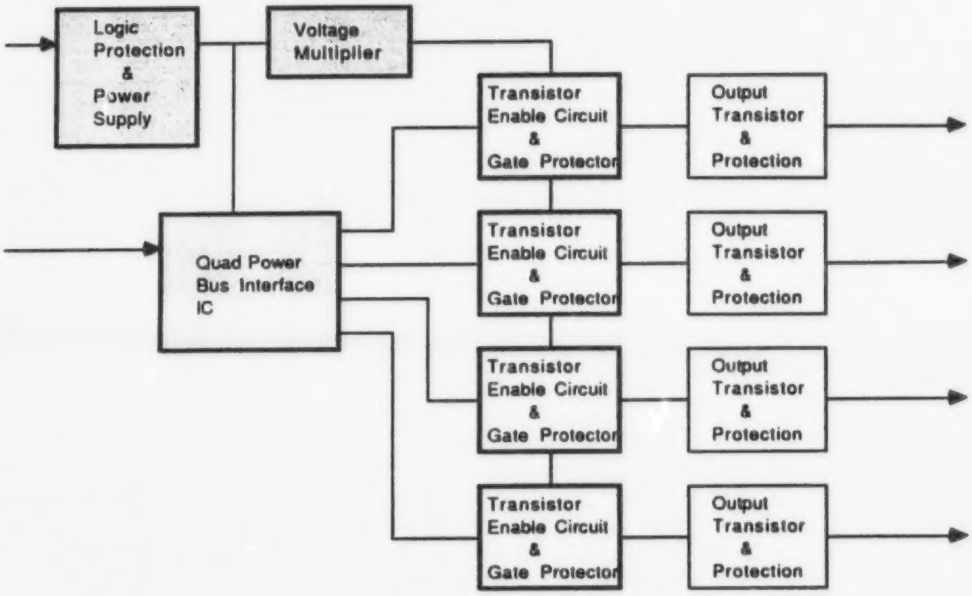

Logic Protection & Power Supply
Voltage Multiplier
Transistor Enable Circuit & Gate Protector
Output Transistor & Protection
Quad Power Bus Interface IC
Transistor Enable Circuit & Gate Protector
Output Transistor & Protection
Transistor Enable Circuit & Gate Protector
Output Transistor & Protection
Transistor Enable Circuit & Gate Protector
Output Transistor & Protection

Figure 26 Quad Class A

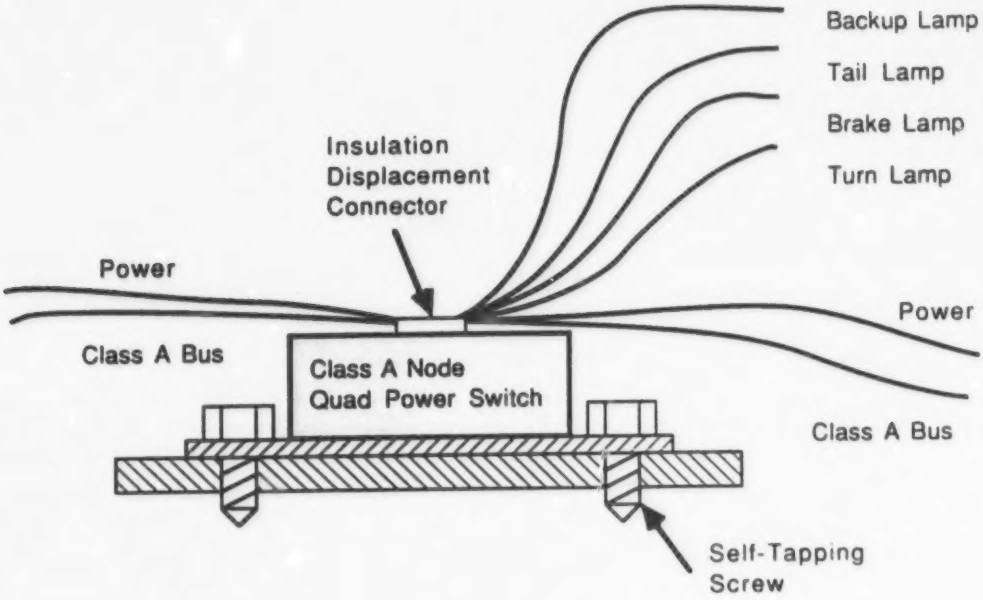


Figure 27 **Possible Class A Package**

6.4.2.1. Switching Requirements

Two basic switching circuits are possible: the high side switch and the low side switch. The high side switch switches the power supply voltage to the device. The low side switch switches the ground. Low side switches have the following disadvantages:

- there is a risk of shorting out the power supply during maintenance. This is possible because the supply voltage is present even when the load is turned off; and
- leakage current flowing from the load to the chassis can cause problems in a salt-laden, high-moisture environment because a constant voltage exists at the load [11].

Low side switches are easier to implement than high side switches due to the differences in the N material and P material used in the power transistors. In power MOSFETs, the P channel devices take twice the area that the N channel devices (with the same current rating) require. N channel devices can be used for high side switches if some form of voltage booster is used to drive the gate. The gate must be switched approximately 5 V - 12 V above the output voltage. Smart switches will soon be prevalent with this kind of feature built-in.

The power switches must be protected from potential transients. From some initial design attempts it is best to choose devices which have enough source to drain voltage to withstand the load dump transient. The other transients can be handled using an integral body zener diode (a feature used in the Motorola "E" series of power MOSFETs, or by an external transient suppressor.

Table 23 lists a number of potential transistors to use as power switches. 12 V power switches require a V(BR)DSS of at least 120 V to withstand the load dump transient. 24 V switches require at least 240 V. The overall best device to use for 1 A loads would be the MTP5N40E which is an N Channel device. This device costs $1.41 in 100s. It has built-in transient protection and can withstand 400 V which is good for reliability (external transient protectors cost approximately $0.65 in 100s). Short circuit protection would have to be provided externally.

Short circuit conditions can not be tolerated in the solid state designs because the short circuit current will not always trip a breaker because the current is limited by the "on" resistance or forward conductance of the transistor. The transistor will eventually overheat and be destroyed. The simplest short circuit protection technique is to use a SENSEFET with sense terminals to drive a transistor in order to short the gate. At the present the SENSEFETs are not so plentiful (although Motorola has recently introduced several new members in the series) and the ideal device should also include transient protection. For now it is best to use an external resistor to sense current flow, but this is at the expense of reduced voltage to the load and increased complexity.

Printed-circuit board (PCB) relays are quite inexpensive and they are not susceptible to the transient conditions and failure from short circuits like the power transistors are. Relays rated with 10 A contacts cost $0.68 in quantities of 10,000. If these devices short, a breaker would trip and keep the device from damage. In the short term relays will likely provide the bulk of the switching requirements for the body systems The main disadvantages with relays are that they wear out and have lower reliability than solid state devices. The wearout mechanisms will prohibit them from being used in applications such as turn signals and brake lights.

In the long term smart switches will be used. These devices will have current limiting, transient protection, thermal overload protection and a built-in interface for the multiplexing system. Hopefully new packages will be developed so the devices can be installed on the vehicle without additional packaging requirements (a package with insulation displacement pins would be ideal). The one main drawback with the new devices will be that they will primarily be designed for the automotive market which has less severe transient specifications.

6.4.2.2. Packaging Considerations for Power Switches

Figure 28 demonstrates a possible connection between a load and a Class A bus. The Class A power switch may be best implemented with a built-in insulation displacement connector in order to eliminate the requirement for specialized harnesses or jumpers at each node. With the insulation displacement connector, the power and data bus wires are just pressed onto the top of the switch as they pass by. Not only does this make an electrical connection, but it can be used for fastening the wires to the chassis as well.

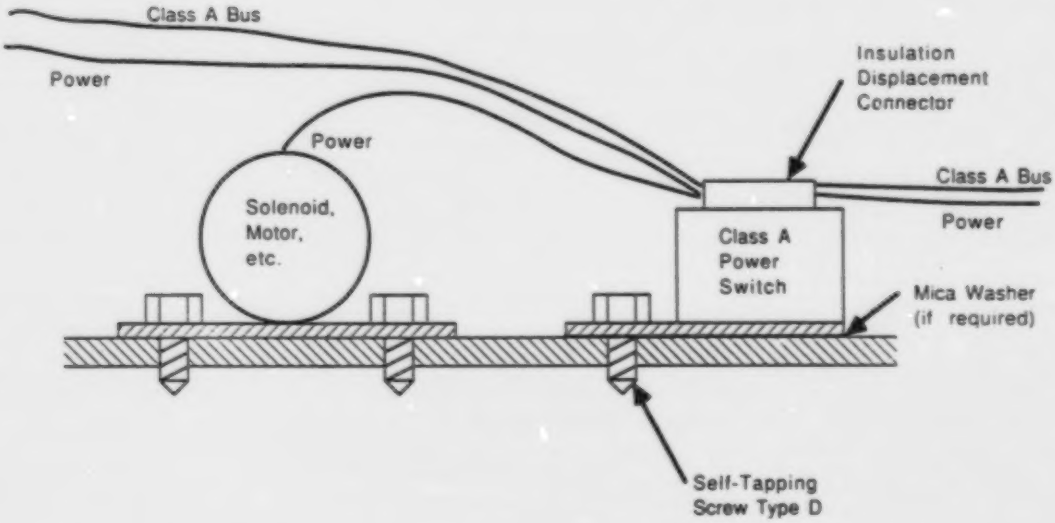

Class A Bus
Power
Insulation Displacement Connector
Power
Class A Bus
Solenoid, Motor, etc.
Power
Class A Power Switch
Mica Washer (if required)
Self-Tapping Screw Type D

Figure 28 **Possible Connection Between Load and Class A Bus**

With the above technique, the power and data bus wires can be wired in longer lengths without the need for specialized harnesses. This will also facilitate the addition of optional equipment.

For many of the devices on the coach the package and wiring must be able to withstand a salt spray environment. The materials used for the package must either be insulated from the vehicle chassis or be compatible with it according to the galvanic series. The lower chassis of the coach is made of stainless steel. Anodized aluminum can be used for the packaging of the switch. Separate ground leads can be used.

The electrical connections must be sealed against ingress of salt-laden liquid. The wire and the terminal will otherwise easily corrode. To prevent corrosion, the wires can be sealed by coating the connection area with RTV before the stain relief cover is applied.

Figure 29 is a multiplexing interface integrated with the controlled device. The preferred connection would be where insulation displacement connectors are also incorporated right on the device itself.

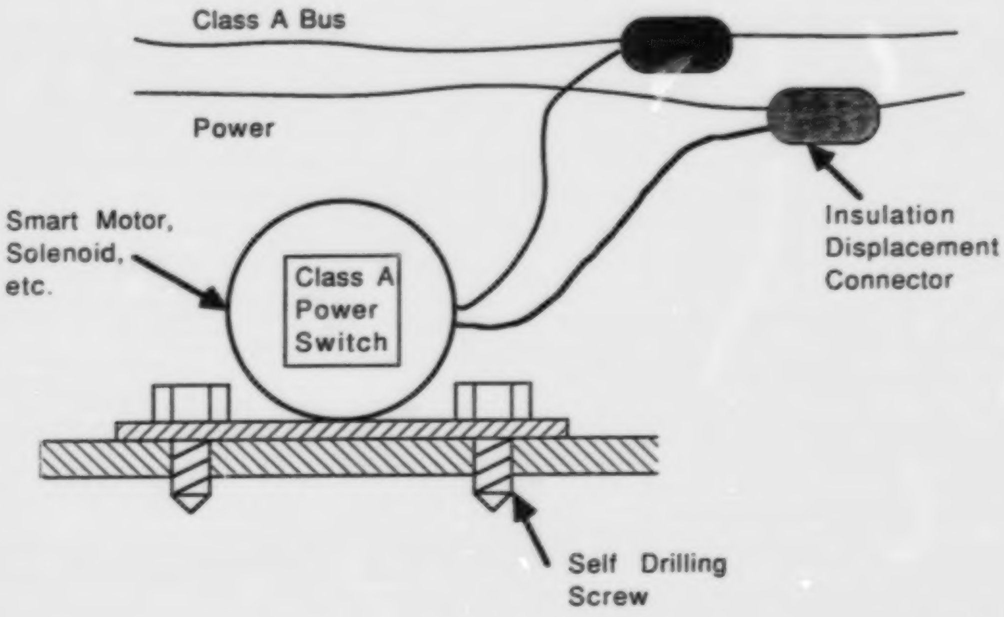

Class A Bus
Power
Smart Motor, Solenoid, etc.
Class A Power Switch
Insulation Displacement Connector
Self Drilling Screw

Figure 29 Integrated Multiplex Interface

More investigation and testing is required to properly evaluate these packaging methods.

The above discussion is more of an ideal approach and requires the node cost to be low. If the node cost is higher, then it is desirable to have multiple loads connected to a common node. This leads to a situation where more wires require termination at the node. If the node is located close to the loads, then there is no problem because the device pigtails can be used directly. Otherwise, specialized harnesses are required. The rear tail light assembly is an example where more than one load can be switched efficiently by one node. The main disadvantage is the introduction of an additional part type.

Potential Class A node prices are listed listed in Table 24. It should be noted that these estimated prices include a 25% labour charge and 50% markup.

Table 24 Typical Class A Node Cost Breakdown

Description	Cost
Single 1A P Channel High Side Switch (12 V)	$16
Single 1A N Channel High Side Switch (12 V)	$14
Single 1A N Channel Low Side Switch (24 V)	$11
Single 1A N Channel High Side Switch (24 V)	$14
Single 10 A Relay Switch (12 V/24 V)	$9
Quad 1A P Channel High Side Switch (12 V)	$41
Quad 1A N Channel High Side Switch (12 V)	$31
Quad 1A N Channel Low Side Switch (24 V)	$23
Quad 1A N Channel High Side Switch (24 V)	$29
Quad 10 A Relay Switch (12 V/24 V)	$13

One possible Class A node package would be to have a small box made of extruded aluminum, containing an integrated insulation displacement connector, as shown in cutaway in Figure 30 and 31.

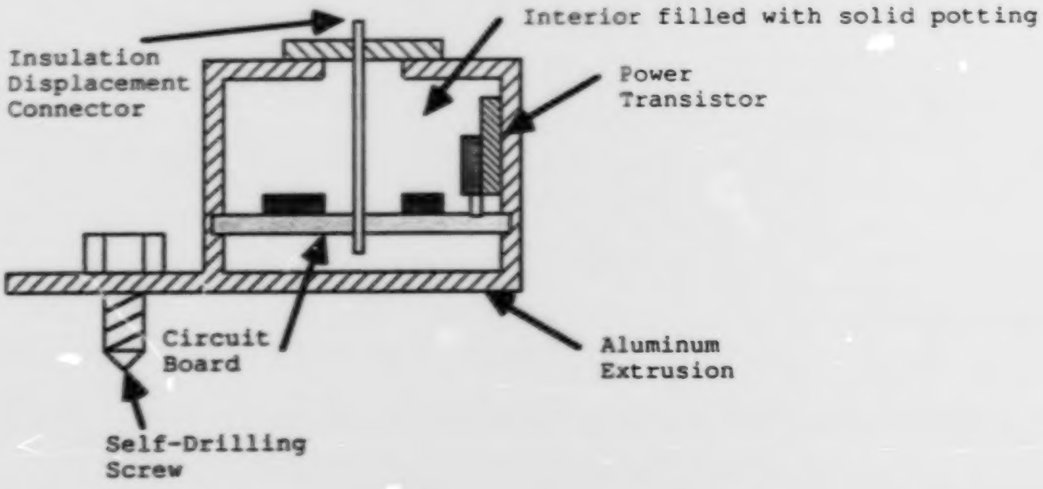

Interior filled with solid potting
Insulation Displacement Connector
Power Transistor
Circuit Board
Aluminum Extrusion
Self-Drilling Screw

Figure 30 Possible Class A Packaging Scheme Cutaway

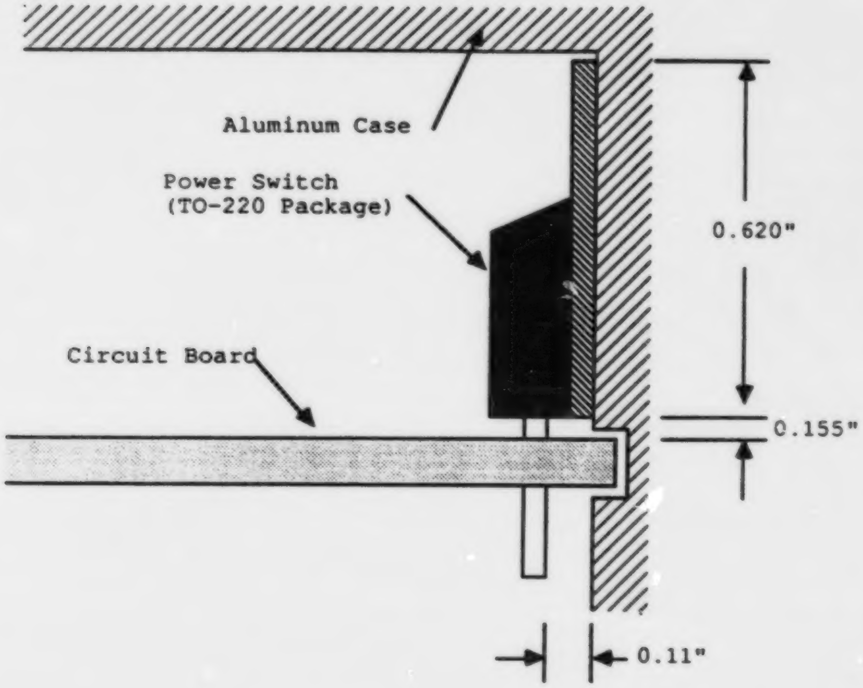


Figure 31 **Detail Cutaway of Possible Class A Package**

6.4.3. Class B Node Design

6.4.3.1. Requirements

Class B nodes will be used as gateways to Class A networks. The Class B bus will also provide the data path between the various subsystems and the dash or diagnostic port.

Input/Output Requirements

The Class B node will be fitted with a Class A bus driver and receiver. This allows the function of the node to be extremely flexible since the hardware to implement different applications is external to the node. Power switches and input sensors can be added as necessary to the Class A bus. The result is that the Class B hardware is fairly general in nature and the same design can be used in several locations.

Some hardware functions cannot be satisfied with the Class A network. These include:

- obtaining high speed pulse data from the speed sensors or RPM indicators; and
- switching high speed outputs such as those required for PWM control.

Currently, the Class A CSC multiplexing system does not support continuously variable analog data which would be needed for the oil pressure or water temperature sender units. In the short term these signals will have to be processed directly by a Class B node. Switched data from sensors can easily be handled by the Class A nodes.

Specialty Class B nodes will have to be designed to perform the following functions:

- drive the dash display;
- drive the touch screens;
- generate sound for driver feedback including chimes, turn signal clapper, lavatory emergency buzzer, etc.; and
- provide PWM control for defrost motors or electric windshield wiper control.

Functions such as these require special hardware in the Class B node. Other Class B nodes will be more "generic".

In-Circuit Programming

For Class B nodes having identical hardware, it makes more sense to specify the function of the node once they are installed on the vehicle. Software revisions may also have to be changed to correct bugs or incorporate new features. Without in-circuit programming, separate part numbers have to be issued for the same basic part whenever the software affects the part's function. On-board node programming of the device allows the same part to be used interchangeably in different applications. This, however, increases the node cost and affects the manufacturing and maintenance requirements.

In-circuit programming can simplify field service inventory requirements by reducing component variability; scrapping or maintaining the inventory of old part types is reduced. This is at the expense of having the node programming capabilities in the field and increased node costs.

The node programming can be performed by the multiplexing system on the coach (using a switch panel or dash display for the operator interface) or by using the diagnostic tester.

There has to be some means of obtaining the latest software revision. If a PC is used for the diagnostic tester, it is likely not too expensive for software to be distributed via modem to the various service depots. Changes will not be very frequent.

In-circuit programming has a large affect on the manufacturing and field service requirements and requires more investigation before a final decision can be made.

6.4.3.2. Hardware Design

Figure 32 shows a block diagram of a Class B node. The various blocks will now be discussed.

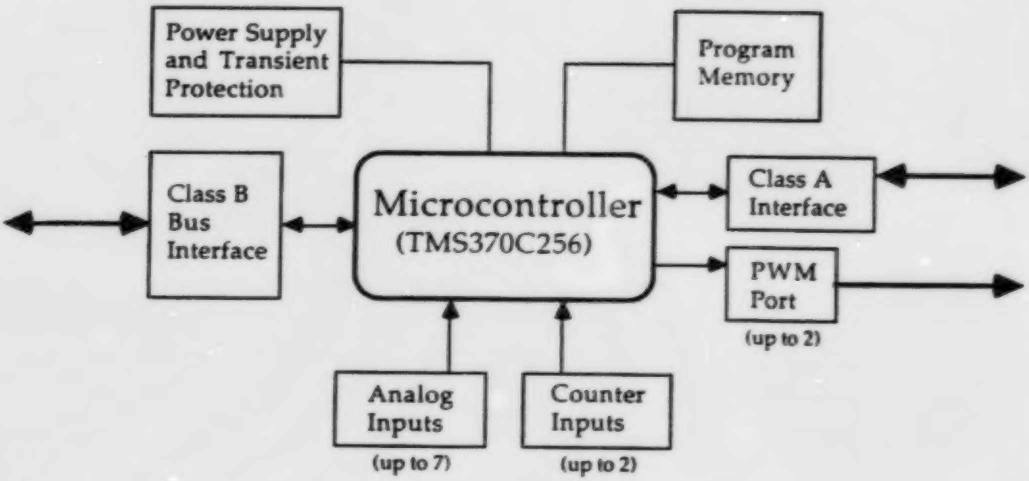


Figure 32 Block Diagram of a Class B Node

Class B Bus Interface

The Class B bus can be implemented using J1708 initially. Later the design can be converted to J1850 or CAN (Class C) if desired. Much of the software will be independent of the actual hardware.

The circuit required for J1708 is shown in Figure 6.

Class A Bus Interface

The current choice for the Class A network is the CSC protocol. This can also be easily changed. An IC is available from Cherry Semiconductor to implement the bus interface (this IC may be proprietary to Chrysler but there is probably no difficulty in obtaining it since Chrysler wishes other parties to use their technology in order for the CSC bus to become an eventual standard).

Microprocessor

The current choice for the microprocessor is the TMS370256FNA. This processor provides an 8-bit A/D converter, 512 bytes of EEPROM (for storing address, diagnostic information, time, etc.), and interfaces to standard program memory ICs without glue logic. It is also low cost. Processors with built-in ROM cost less in volume, but are not recommended due to the low MCI manufacturing volumes (typically 5,000 or more units must be purchased to make this economically attractive).

Program Memory

There are several options for the program memory which are dependant on the node programming method:

- **One Time Programmable (OTP) EPROM** - this is the lowest cost alternative. For in-circuit programming extra circuitry is required. More than one programming operation can be performed on the EPROM provided new areas in memory are being programmed. If the device has large capacity, it is possible to accommodate several revision levels of the software before the node has to be discarded.
- **Conventional EPROM** - this uses ultra violet light for erasing. It is not much more expensive than OTP EPROM. For programming revisions, the EPROM can be potentially erased through a window in the node packaging, although this is not that desirable from a manufacturing and maintenance perspective.
- **Flash EPROM** - This can be electrically erased, but is programmed similar to conventional EPROM. Currently it is approximately three times the cost as conventional EPROM. but costs are expected to be comparable with EPROM in the long term.

Power Supply and Transient Suppression

A voltage regulator is required and means to isolate the internal power supply from the various vehicle transients. The node will not require significant power, and the best means of isolation may be to use an active current source driving a transient suppressor. For in-circuit programming, an automotive voltage regulator such as the Motorola TCF5600 can be used. This device can selectively provide the high voltage necessary for programming Flash and EPROM memory.

Input Transient Protection

Input transient protection can be provided using series resistors and diodes or a clamping array such as the Motorola TCF6000 which can clamp up to six inputs.

6.4.3.3. Packaging Considerations

The packaging will be very important for Class B. It is desirable to have the nodes as generic as possible and therefore more connections should be available from the module than would normally be hooked up. This usually means custom harnesses are required to connect to the module. All signals could be connected to an insulation displacement connector on the top of the module if enough room is available. The preferred signals to connect to the top are the multiplexed bus and power since these signals are typically daisy chained. The other signals will likely terminate near the module so they could be connected to an additional connector on the side of the module.

The packaging could be implemented in a similar fashion as the Class A modules. The unit will not be too expensive so there will be no need to repair it.

One alternative packaging option to the insulation displacement connectors is to use a stud block type connector strategy, as shown in Figure 33.

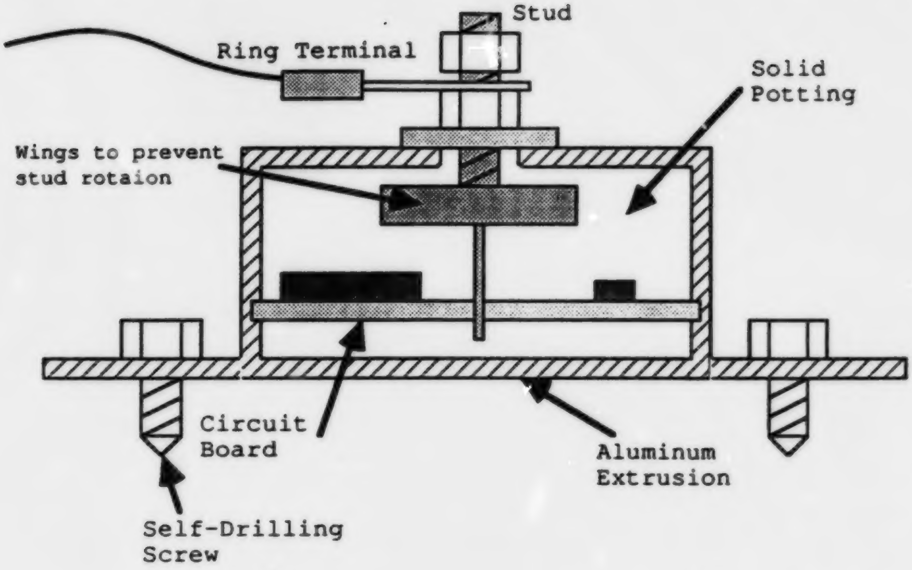


Figure 33 **Stud Block Type Packaging Option**

The estimated cost for a Class B node is approximately $50 in quantities of 100. This cost includes a 25% labour charge and a 50% markup. An additional $10-$20 is required for the in-circuit programming capability.

6.4.3.4. Switch Panels and Dash Display

The nodes servicing the switch panels and the dash display will likely be installed on the same circuit boards as the other electronic hardware necessary to implement the node function. These circuit boards are already protected by the dash hardware and so need no external packaging. The boards can be spray coated to protect them from moisture due to condensation.

6.4.4. Software Structure

Object oriented programming will be important in the multiplexing environment. This will make the system very flexible and easy to adapt to various hardware implementations.

7. COST/BENEFIT ANALYSIS

7.1. Introduction

There are many factors which affect the overall cost/benefit of a major change in design such as this one. Aside from obvious manufacturing cost savings there are a number of not so obvious costs and benefits. Other benefits are:

- ease of implementing options;
- reduction in drawing control;
- reduction in parts stockage;
- space savings;
- increased functionality in present and the future;
- reduced maintenance costs;
- increased vehicle safety;

Other costs are:

- need for new engineering skills and equipment;
- need for new manufacturing skills and equipment;
- need for new maintenance skills and equipment;
- risk exposure.

It is desirable to eliminate specialized controllers and control relays, such as:

- HVAC controller;
- turn signal/hazard flasher;
- triple function protection device;
- clappers and buzzers.

These various control functions can be performed by microcontrollers already present in Class B nodes. It is this elimination of specialized controllers and control relays which will have the most significant impact on cost savings.

7.2. Expected Reduction in Manufacturing Costs

Evaluating the reduction in manufacturing costs is not so straightforward. There is a large amount of interdependence between systems due to resource sharing so it is difficult to say exactly how much a particular system conversion is saving.

Isolated conversion of individual subsystems may not provide any economic benefit. Significant savings begin to surface when doing an integrated conversion of several subsystems; in this way the newly converted subsystems benefit from multiplex hardware already present, significantly reducing development and hardware cost.

A description of the implementation for the predominant systems is contained in Appendix A. The estimated manufacturing savings for a number of subsystems are contained there and are summarized in Table 25. Details of how these values were obtained are presented in Volume II.

Table 25 Estimated Manufacturing Savings

System Name	Potential Savings
Switch Panels	$200
Dash	$250
HVAC System	$250
Engine Control System (DDEC)	$75
ATEC Transmission Control	$100
Engine Starting System	$80
Rear Tail Light Clusters	$(20)
Remote Box	$150

7.3. Other Costs

7.3.1. New Manufacturing Skills

The installation of the multiplexing components and the wiring will not be much different for the existing system. The main new skills to acquire will be those needed to set up and debug the system. System set up should be as automated as possible.

During manufacture, nodes can be programmed during installation on the vehicle. A diagnostic computer can be connected to the bus in order to aid the operator in the installation. The operator can be prompted where a node is to be placed and advised when a node is defective or has caused a bus fault.

If the system is totally assembled before it is tested, it will be necessary to to isolate improperly installed components. This will be facilitated using a diagnostic computer. Table 26 shows some of the new manufacturing skills required.

Table 26 New Manufacturing Skills Required

Skills Required	Simplified by
Programming of nodes	User-friendly software in programmer
Debugging defective nodes and connections	Expert system in diagnostic tester

7.3.2. New Maintenance Skills

Maintenance personnel will be required to understand the use of the diagnostic computer and be trained on how to troubleshoot bus faults. The trouble shooting will be simplified by having good diagnostic software and being able to separate the bus in various locations. Failed nodes can be detected by the diagnostic software and will simply be replaced.

The logging of intermittent faults by the various nodes will greatly simplify debugging. Since a large amount of information may be available, an expert system will be required to sort it out and convey useful information to the technician.

The maintenance requirements should not be underestimated and the diagnostic software should be extremely thorough. If the software is not thorough enough, then skilled technicians will be required to debug the vehicle (their findings should be used to improve future versions of the maintenance software). New maintenance skills required are shown in Table 27.

Table 27 New Maintenance Skills Required

Skills Required	Simplified by
Use of diagnostic computer	User friendly software
Isolation of cable faults	Proper cable design and debug software
Debug of intermittent faults	Expert system

7.3.3. New Engineering Skills

Multiplexing components will become more available once a standard has been established and more vehicles convert to multiplexing. At that point the need to possess design capability for the node electronics will diminish. OEM manufacturers will then supply modules for interfacing sensors to the multiplexed system and modules for switching power to different loads. Since the modules are relatively low cost, they can simply be discarded.

In the long term, the engineering skills required to implement and maintain a multiplexing system will simplify to writing and maintaining custom diagnostic and control software, and evaluating the effects of node loading when high-speed Class C systems are used. The new engineering skills required are depicted in Table 28.

Table 28 New Engineering Skills Required

Skills Required	Simplified by
Design of node electronics - sensor interfacing - power switching	Eventually will be done by OEMs.
Design of dash display	Eventually will be done by OEMs.
Writing software for driver interface and node controllers	Will require ongoing upgrades as new components are added or improvements are required. This requirement will be simplified by having a standard set of "objects" created in the initial design.
Design of diagnostic tester	Will consist of not much more than a PC with custom software
Writing software for expert system to diagnose system faults	Will require ongoing upgrades as new components are added
Design and maintenance of multiplex bus(s)	Will require ongoing upgrades as new components are added. This requirement will be facilitated by special software packages.

7.3.4. Risk Exposure

In general, risk will be reduced if the multiplexed system is introduced in a well-planned manner and adequate preproduction testing on prototype vehicles is done. Potential areas of risk and means to combat them are shown in Table 29.

Table 29 Methods to Reduce Typical Areas of Risk in Multiplex Systems

Risk	Methods to Reduce Risk
Vehicle accident attributed to the multiplexed system (there is no possibility of this for Class B systems unless the system causes distraction of the driver).	Ensure that the multiplexed system failsafes into a safe operating mode which is not distracting to the driver. Do not introduce drive-by-wire until the reliability of the multiplexed system has been established.
Dissatisfaction of operators due to increased vehicle failure rate.	Design the system for reliability and use reliable components. Ensure design faults are eliminated by proper design procedures and extensive preproduction testing. Ensure that the vehicle will not be totally immobilized in event of a multiplexed system failure.
Dissatisfaction of operators due to increased maintenance costs	Ensure mean time to repair is low. Ensure that proper diagnostic equipment is distributed and maintenance personnel are trained in its use before multiplexed coaches must be repaired. Use a standard diagnostic tester.
Dissatisfaction of maintenance personnel due to inability to diagnose the system failures properly.	Evaluate the diagnostic algorithms with extensive preproduction testing. Provide proper training materials for the use of the diagnostic system; e.g. trouble shooting examples on video.

Dissatisfaction of drivers due to misunderstanding of new vehicle operation.	Ensure the driver interface is intuitive and structure it so the driver feels important. Perform preproduction tests with a variety of drivers so the optimum design can be achieved.

7.4. Other Benefits

7.4.1. Ease of Implementing Options

Due to the modular nature of the multiplexed bus it is a simple matter to remove or add nodes to the system. Connections to the bus are done via insulation displacement connections or using standardized connectors and can be accomplished easily and without affecting the rest of the system.

Engineering time to incorporate new options is also reduced. Designing new nodes for the multiplexed system is simplified by the fact that the bus has a standardized connection interface, as well as standardized driver and maintenance interfaces. These interfaces, since they already exist, need not be re-designed each time a new node requires development.

Options will become specified in software without so much hardware and harness changes. The dash will be able to adapt to devices as they are added to the system.

7.4.2. Reduction in Drawing Control

The multiplexed wiring can be implemented with insulation displacement connectors so that the bus and power wires can be run using single wires. Harness drawings can be eliminated to a large extent, although custom harness may be required for connection to the devices. The number of drawings required for wiring harnesses will be greatly reduced.

7.4.3. Reduction in Parts Stockage

There will be a reduction in part variation resulting from the fact that the functioning of the part can be programmed in software. For example, the temperature controller will no longer be required. Name plates for all the switches and tell/tales will no longer be required. A large number of specialty harnesses will be eliminated. Common parts can be used for sensor interfaces, power switches and node modules

7.4.4. Increased Functionality in Present and Future

It is easy to improve the operation of various subsystems through the use of microprocessor control already present in the nodes. Major changes in the way things are implemented can result from this. Existing systems to primarily benefit are the engine starting system, HVAC system and tell/tale display.

The multiplexed system can also provide the information already available on the DDEC engines to the driver. Parameters such as instantaneous fuel rate and total fuel used are examples.

In the future lower cost systems can be used to replace existing ones. For example the video backup system could be replaced by an ultrasound system. One of the graphics displays on the dash can display the feedback from these sensors graphically in relation to the back of the bus.

7.4.5. Miscellaneous Ideas to Provide Increased Functionality and Reduced Cost

In generating the subsystem breakdown several other ideas for increasing functionality and/or reducing cost became apparent.

Vehicle security can be implemented at no cost. The driver's switch pad can be used to enter a password. There would be no way the vehicle could be operated without the password.

There appears to be much maintenance required for components which operate on air. Components such as the baggage compartment locks, radiator shutters, and fan belt tensioners could be implemented using electric gear motors. High torque can be achieved with low cost gear motors.

The windshield wipers and washer could be converted to electric. This will allow pulsed operation of the wipers.

The levelling of the air suspension system could be controlled electronically. An electronically variable pressure regulator could be developed for this purpose. A number of control valves could be eliminated if such a device existed.

7.4.5.1. Sensor Reduction

Potential exists to reduce the number of sensors in the multiplexed system over those used in the present coach. The most obvious examples are the low air pressure switch and the air pressure sender unit; the low oil pressure switch and the oil pressure sender; the two hot engine alarmstats and the water temperature sender; the low and high refrigerant pressure switches used on the A/C compressor (instead of one continuous output pressure sensor); and the speedometer sensor, the speed sensor used for the cruise control, and the ATEC output shaft speed sensor.

It could be argued that it is a good idea to have redundant sensors in order to improve reliability. The major savings in multiplexing do not depend upon sensor reduction but also come from the elimination of control relays and labour intensive items such as the dash and harnesses.

7.4.6. Ease of Implementing Field Upgrades

Having a standardized bus interface greatly reduces the skill, effort, and time needed to install or remove nodes from the bus. The supporting hardware and software on the coach itself could perform most of the task of integrating any new node with the existing system.

7.4.7. Space Savings

Multiplexing will reduce the space required by large harness bundles. On the present coach this is not a major problem. The worst problem exists in getting signals from the dash and the front junction box to the roof and parcel racks. In the initial design, multiplexing is not used for the roof and parcel rack subsystems due to the fact that most of the wires going to the roof are required to bring the power to the components. In the future, when multiplexing is used, power can be routed from the back of the coach or directly from the battery box to the roof in order to relieve congestion.

The five channel entertainment system uses the HVAC ducts for wiring the systems on the seats. Using multiplexing for these audio signals would not be cost effective.

7.4.8. Reduced Maintenance Costs

Maintenance costs can be reduced by providing better diagnostic information about intermittent failures. The cost of preventative maintenance can also be reduced by monitoring such things as the differential pressure across a filter. In this way filters need only be changed when required rather than on a routine basis.

One major coach operator claims that it costs $0.36 CAN/mile to maintain a coach. This is quite substantial considering a coach can easily put on 500 miles/day. It amounts to $65,700 a year. More work should be done in this area to breakdown the costs and determine how the customers perceive the benefit of increasing diagnostic capability in order to reduce maintenance costs.

7.4.9. Increased Vehicle Safety

Increased vehicle safety will result largely from the ability to add new systems to the vehicle without much difficulty. Tire temperature and pressure systems, and collision avoidance systems are examples. The addition of these systems will be much more economically feasible with the multiplexed system.

The availability of more diagnostic information can be used to predict potential breakdowns and thus reduce danger to passengers.

Diagnostics from rear signalling lights can make the driver aware of a failed signal or brake light.

The reliability of the vehicle electrical system will remain approximately the same or improve.

8. DIRECTIONS FOR FUTURE WORK

In considering the directions for future work, the following are important:

- developments should be unique to coaches so that there is no duplication in eventual third party R & D;
- close attention should be paid to emerging standards; and
- advantage should be taken of new developments in multiplexing as they appear.

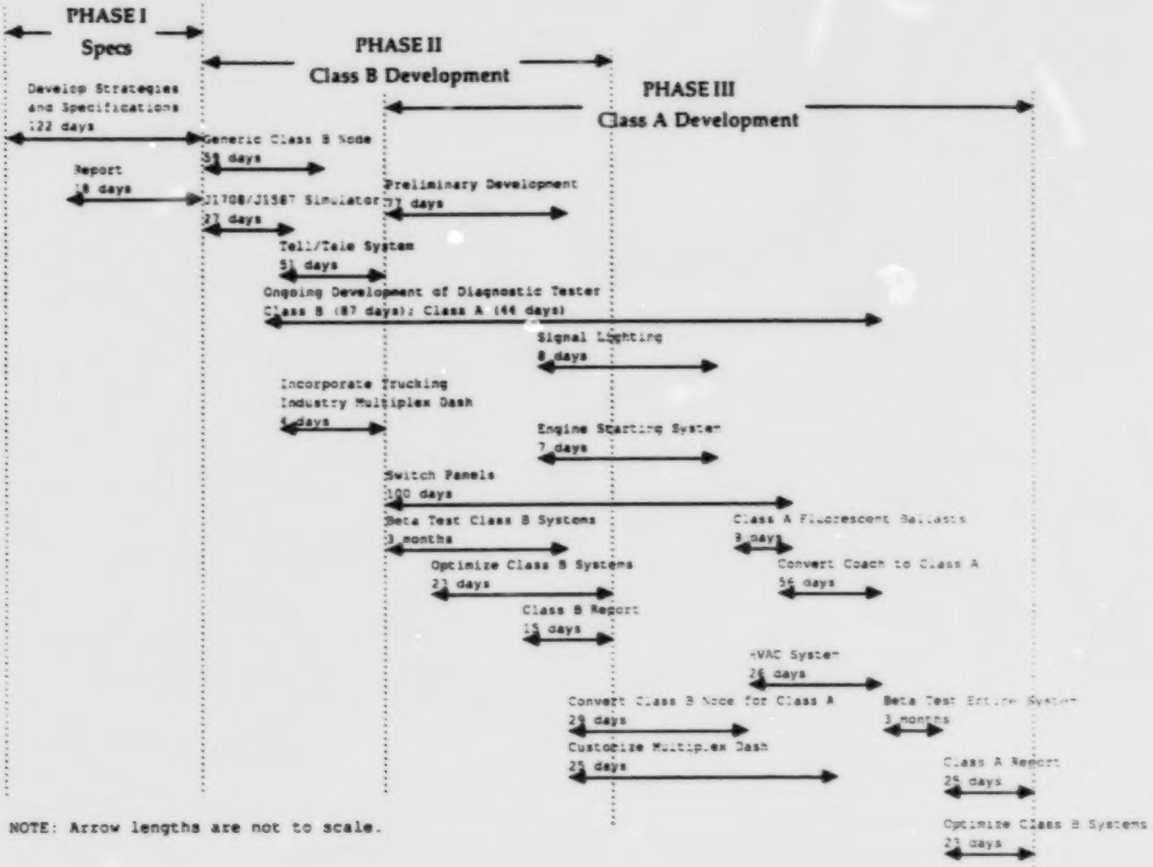
8.1. Technology Constraints

Currently J1708 and J1587 have matured sufficiently so that development with these systems can proceed at any time.

Class A systems are still in their infancy and automotive systems should emerge in the next year or two. The CSC system appears to be the most promising and sensor interfaces are already available. The key missing link for Class A development is a suitable inexpensive smart power switch which can handle the coach transient environment. The trucking industry will also require these parts. Due to the potential sales volumes with the combined truck and bus industry, semiconductor houses may decide to pursue the market.

8.2. Multiplexing Development for Coaches

Figure 34 shows a graphic representation of the first three phases of the recommended project work for introducing multiplexing into intercity coaches. Although it is not to scale, it does show the approximate time relationship between the various tasks.



NOTE: Arrow lengths are not to scale.

Figure 34 Recommended Project Timeline Showing Three of the Five Development Phases

In Phase I, the outstanding technical issues will be resolved and specifications will be written for the multiplexing components. These specifications will be consistant with the long range plans for the manufacture and maintenance of the vehicles.

In Phase II, a low-risk Class B multiplexing system centered around the conversion of the tell/tale system will be incorporated into the coach. A preliminary diagnostic tester will be developed and the system will be thoroughly tested.

In Phase III, Class A systems will be incorporated into the multiplexed system. The initial multiplexed system will be upgraded for compatibility with the new components. At this point the vehicle wiring will be totally redone. Extensive testing of the system will be performed.

In Phase IV, ongoing developments in Class C systems will be monitorred and dianoctic capabilities will be added to the diagnostic tester to handle the intial Class C systems.

In Phase V, new subsystems will be developed and old ones improved to take advantage of the improved communications and diagnostics afforded by the multiplexing environment. Some mechanical subsystems will be optimized using electronic control.

The details of the individual phases will now be discussed.

8.3. Phase I: Determine Strategies and Specifications

8.3.1. Determine Realistic Coach Transient Protection Requirements

Tests will be conducted to measure the transients in the coach power system. An investigation into alternators and regulators which minimize transient signals will be conducted. Effort will be made to make the transient environment in a coach compatible with automotive components. Analytical models will be generated (and data will be gathered to verify them) which relate wire length and proximity with the strength of the coupled signals. Specifications from the SAE will be reviewed and a final transient specification will be generated.

8.3.2. Determine Effects of Arc Welding on Coach Electronics

Some preliminary investigation will be performed to determine if anyone has already done work in this area. An analytical model will be generated to predict the effects. Tests will be conducted to verify the accuracy of the model and generate a specification.

8.3.3. Develop Long-Term Wiring Diagram for Coach Power Distribution

A detailed wiring diagram will be generated which defines the distribution of 12 V and 24 V on the vehicle if a full-blown multiplexed system is installed. Attention will be given to specify components and a wiring distribution which minimizes the effects of transients. The diagram will show the size of feeder wires, the location of circuit breakers. The use of junction boxes will be minimized.

A means of activating the multiplexing system will be sought which avoids draining the batteries when the coach is parked for extended periods. Details will also be considered for the grounding of various subsystems in locations exposed to salt spray.

8.3.4. Develop Long-Term Wiring Diagram for Coach Multiplex System

A wiring diagram will be generated to provide the long term goal for the multiplex system. This will be done to ensure that intermediate steps are consistent with the long range plans.

8.3.5. Develop Packaging and Mounting Techniques for the Multiplex Components

Multiplex components will be installed in various locations of the coach. Some will be exposed to extreme temperature variations and salt spray. Steps have to be taken to ensure that the materials selected and the mounting hardware used will not cause corrosion of the vehicle or the multiplexing components. Packaging requirements will be specified for the various installation environments possible.

8.3.6. Develop Wiring Techniques for Multiplex Components

The method used for wiring and installing the multiplex system will have a large impact on the labour component of the manufacturing costs. The number of custom harness drawings required, parts inventory, and serviceability is also affected.

Wiring techniques will vary with the class of multiplexing. Performance issues relating to impedance matching and noise immunity will be considered.

Various wiring techniques will be evaluated to determine the technique giving the best compromise between cost, performance, reliability, serviceability, and documentation requirements.

Tests will be performed where necessary should insufficient data be available from the manufacturers or in the literature.

8.3.7. Evaluate Usefulness of Generic Nodes

Generic nodes will have a core set of hardware and the ability to be programmed either on the vehicle or in the shop. Using generic nodes will reduce component costs and parts inventory. The disadvantage is the slight increase in material cost and the cost of programming the nodes (which will likely be done by untrained personnel).

Cost tradeoffs will be evaluated. Both maintenance and manufacturing scenarios will be addressed. The cost of supplying redundant hardware will also be addressed.

8.3.8. Develop Maintenance Strategies

Maintenance depots will eventually have to be equipped with diagnostic equipment and provided with the necessary training to service the multiplexing system on the coach. The choice of equipment and means of keeping the equipment up to date with the latest changes in vehicle equipment will have a large impact on maintenance integrity and costs. Means exist to electronically detect components from a bad production lot or built to a defective design revision. Maintenance depots can benefit from routinely distributed electronic "service bulletins" which will identify the faulty components and define means of repair. Field upgrades can be performed using a computer to detect the compatibility with existing equipment and provide the operator with prompts on what to do next.

An investigation will be made into the current equipment and strategies used in the automotive and trucking industries. The cost of using standard PCs and the cost of distributing floppy disks or providing electronic mail will be addressed. The cost of providing training on video tape will also be addressed.

A suitable method for accessing data from the multiplex bus will be determined. This will consist of either a simple connector or an infrared link.

8.3.9. Develop Long Term Fault Tolerance Strategies

The fault tolerance of the various subsystems will be categorized to ensure that the multiplex system can provide the needed reliability or contingency measures. A detailed list of all subsystems will be generated along with failsafe states and the degree of fault tolerance required. The probability of failures will be traded off against the cost of protection for the critical subsystems. The fault tolerance requirements of the various buses will be defined.

8.3.10. Develop Hardware Reliability Plans

Procedures will be outlined to ensure the reliable development of the hardware. Design reviews will be be conducted regularly throughout the hardware development in conjunction with MCI personnel to ensure the integrity of the designed equipment. A reliability prediction program will be used to predict the reliability of the hardware modules. An overall reliability budget for the multiplex system will be generated.

8.3.11. Develop Software Reliability Plans

Plans will be generated to ensure the reliable development of the software. It is expected that Computer Aided Software Engineering (CASE) tools and object oriented programming will be used in the development so that the software is well organized. Design reviews will be conducted on a regular basis to ensure consistent thoroughness and quality.

8.3.12. Summarize Specifications and Generate Report

A report will be generated documenting the results of the work performed during this phase. Specifications for the multiplexing nodes including reliability, packaging, wiring technique, temperature range, salt spray exposure, etc., will be summarized and included in the report.

8.4. Phase II: Develop Class B System for the Coach

The Class B system will be based on SAE J1708/J1587. The system will handle data coming from the DDEC II engine and the ATEC II transmission as well as handle data normally displayed on the dash tell/tales. The goal of the project will be to become familiar with the idiosyncrasies of J1708/J1587 and characterize the performance of the Class B system in the coach environment. This will be done by installing a prototype system on the coach and analyzing its performance through extensive testing.

8.4.1. Develop Tell/Tale Driver Interface

Effort will be expended to determine the best driver interface which retains the simplicity of the existing T/T system yet provides improved diagnostics. Eventually the location of failed external lights, as well as fault codes or messages from the engine and transmission, will be indicated to the driver. The use of various sounds to augment the message to the driver will be investigated.

Ideally the interface should be as generic as possible, so some form of character display or graphics panel is desirable. The cost of various displays will be compared to determine the optimum cost/performance tradeoff.

8.4.2. Develop Simulator for SAE J1807/J1587

The J1708/J1587 simulator will be used to verify software functionality without the hardware. The simulator will be able to generate the full complement of bus messages and model randomly occurring data errors. Communications will be time-logged to analyze latency and throughput.

8.4.3. Develop Tell/Tale Electronics

The new system will incorporate some measure of transparent expansion/reduction so the tell/tale system can accommodate diagnostics and warnings from a variety of subsystems and be potentially compatible with the trucking industry. The state of J1587 will be reviewed and if necessary enhancements will be proposed to the SAE to provide the generic functionality of the T/T system.

Software will be written and a circuit board will be generated to drive the T/T display. Audio feedback will also be available. Packaging design will be performed.

8.4.4. Develop Generic Class B Node

A generic Class B Node, compatible with J1708/J1587, will be designed to pick up signals in the the front and rear junction boxes. A separate node will be located in each junction box. Signals will be input to the parallel ports of the on-board microprocessor and special harnesses will have to be designed to connect the nodes to the signals in the junction boxes.

The node will incorporate in-circuit programming to allow the same hardware to be used in more than one location.

The design will be easily modifiable in the future to drive a Class A interface or use a different Class B bus.

8.4.5. Develop Dash

An LCD display and electronic assembly used by the trucking industry will be used for the initial dash prototype. This dash provides engine RPM and road speed, as well as instantaneous fuel consumption, all sourced from the J1708/J1587 bus. The mechanical air pressure gauge will be retained.

8.4.6. Develop Diagnostic Tester

The initial core software for the diagnostic tester will be be developed as well as software to diagnose the Class B system. A standard PC will be used for the tester.

A Class B interface board will be developed to interface the PC to the multiplexed bus. CASE tools and object oriented programming will be used in the development of the software.

8.4.7. Beta Test of Class B System

The Class B system will be installed on a coach and testing will be conducted. Test results will be used to establish the reliability of the design and to determine what can be done to enhance performance and reduce cost in future designs. Data errors on the bus will be monitored to characterize the noise immunity of the system. Component failures will be investigated to determine the exact cause of failure. Feedback from the drivers will be gathered to determine where the driver interface can be enhanced.

8.4.8. Cost Analysis and Report on Class B Implementation

A detailed cost analysis will be generated detailing the cost of installing the Class B system on the coach. A report will be written detailing results of the beta test and recommending potential design improvements.

8.4.9. Optimize Class B Multiplex System Design

Data from the cost analysis and beta tests will be used to optimize the design of the Class B multiplexing system.

8.5. Phase III: Class A Development

A Class A system will be designed for the coach. The design will proceed in stages. First, the signal lighting on the coach will be converted. This will allow the driver to be aware of failed signalling lights and should improve vehicle safety. Second, engine starting will be converted to Class A operation. Finally, existing switch panels will be converted to touchscreens and the entire coach will be converted to multiplexing.

8.5.1. Select Class A Network and Generate Class A Node Specifications

Initial work has to be done to characterize the noise immunity of the Class A networks. Noise immunity and error checking is not as good as for Class B and Class C systems. Steps have to be taken in the design to ensure that the operation of the power switches can proceed in a way that it will be tolerant to noise on the bus. Feedback from power switches is necessary to diagnose failed bulbs or sockets. Temporary errors from sensor outputs also have to be tolerated.

A Class A network will be selected which provides the best compromise between performance and installed cost. Installed cost is important because the wiring techniques can be quite different for different networks. Special measures can be taken to handle the subsystems requiring a high level of fault tolerance.

Tests will be conducted on the current contenders for standardization to select the best system for the coach environment.

Availability of components which are compatible with the coach power system will also be addressed. Smart sensors will be developed for the automotive industry which are compatible with potential Class A standards. The use of these sensors on the coach will be evaluated.

Specifications for the Class A sensor and power switching nodes will be generated.

8.5.2. Investigate Use of ASIC Design for Class A Power Switches

The ideal smart power device will have the multiplexing interface built-in. These components will eventually exist for the automotive industry, but will not likely be compatible with the power supply and transient environment in the coach.

The costs of developing proprietary parts useful for the coach and trucking industries will be evaluated.

8.5.3. Develop Class A Quad Power Switch

A quad power switch will be developed for the rear tail light clusters. The device will detect malfunctions and provide a status signal on the bus. A circuit board and package will be designed.

8.5.4. Develop Class A Single Power Switch

A single power switch will be developed for use in most power switching applications. The packaging and connection to the bus and power will be key in achieving an economical design. If possible a single smart power device will be used. Effort will be expended to determine if the IC die can be mounted in a custom plastic package directly by the IC vendor.

8.5.5. Develop Class A Pulse Width Modulator (PWM) Node

A PWM node will be developed to drive variable output devices such as the driver's defrost motors and dash display intensity.

8.5.6. Review Smart Motor Developments

Effort will be expended to keep abreast with developments in smart motors. Eventually motors will be available which have the multiplex interface built-in. These devices will be useful for remote control mirrors, blowers, baggage compartment locks, radiator shutter actuators, fan belt tensioners, etc.

8.5.7. Convert Class B Node Design to Handle Class A

A Class A hardware interface will be added to the circuit board. A decision will be made whether to retain the J1708 Class B interface or convert to J1850. Fault tolerance of the Class B system will be reviewed and upgraded if necessary. Software to drive the Class A interface will be written. A decision will be made to retain the J1587 protocol and adapt it for Class A operation or to convert to different standard protocol which may be available when the time comes.

8.5.8. Convert Signal Lighting to Class A

A hall-effect sensor will be incorporated into the turn signal actuator and the hazard switch. Class A power switches will be installed at the light clusters. Diagnostic information will be routed to the T/T system to indicate when malfunctions occur.

8.5.9. Develop Class A Sensor Switch

A sensor switch will be developed to detect switch closures from a number of transducers such as the low oil pressure and low air pressure transducers. A package will be designed which can easily mount to the existing transducers. The transducer vendors will be contacted to see whether the multiplexing interface can be built right into the transducer. Failing this, new sources of transducers will be contacted to see whether smart transducers can be developed with the multiplexing interface built in.

8.5.10. Source Smart Transducers with Built-in Multiplexing Interface

Vendors will be contacted (particularly those producing components for the automotive industry), to determine what sensors are available with the Class A multiplex interface. New methods of measuring things on the coach will also be sought in order to improve functionality, reliability and compatibility with multiplexing.

8.5.11. Convert Engine Starting System to Class A

The function of the triple function protection device will be integrated into the rear junction box Class B node. A Class A sensor will be used to input the necessary dash switches into the front junction box node. A power switch will be used to activate the starter relay. Transmission in neutral, engine RPM, and oil pressure will be available on the multiplexed bus from the ATEC and DDEC modules. Alternator overvoltage can be detected using the A/D converter in the rear junction box Class B node.

8.5.12. Design Class A Fluorescent Ballasts

The ballasts will be redesigned to incorporate a Class A multiplex interface. Diagnostics will be available to detect a failed ballast or bulb.

8.5.13. Develop Class A Driver Interface

A new driver interface will be designed to replace the existing coach switch panels. LCD graphic touchscreens will be used to demonstrate the concept. The graphic panels will facilitate the transparent expansion/reduction of the multiplexing system will replace the graphic or character display of the existing Class B T/T system. Much of the software (including the audio portion) of the T/T system will be retained.

Drivers will be consulted as to preferences. Displays and touchscreens will be sourced. The appropriate source of heating and backlighting for the LCD displays will also be sourced. The software and hardware necessary to drive the displays and touchscreens will be developed. Object-oriented programming techniques will be used for the display software. A prototype will be built and tested in the lab.

8.5.14. Convert HVAC System to Multiplex Operation

The HVAC system will be fitted with Class A pressure sensors, temperature sensors and power switches. Software will be written to perform the temperature controller function. A suitable driver interface will be developed using the touchscreens.

8.5.15. Upgrade LCD Dash Display to Incorporate all Gauges

The prototype dash display will be upgraded to incorporate the full complement of gauges used in the coach. The dash will be designed to complement the touchscreens. Drivers will be consulted for preferences.

8.5.16. Upgrade Diagnostic Tester to Handle Class A System

Software will be written to handle the diagnosis of the Class A system. A hardware simulator will be developed for stimulating and testing the Class A components.

8.5.17. Convert Coach to Class A Operation

The wiring of the coach will be totally redone. One junction box will be retained for housing circuit breakers. Switch panels will be replaced by touchscreens. All circuits on the coach will be converted to multiplexed operation. Effort will be expended to convert the throttle, transmission shifter, and cruise control switches to multiplexing in order to reduce the harnesses required for DDEC and ATEC.

8.5.18. Beta Test of Class A Multiplexing System

The test coach will be driven by a variety of drivers, and feedback will be solicited regarding design improvements. Communication errors will be monitored and component failures will be investigated in detail to determine the exact causes.

8.5.19. Cost Analysis and Report on Class A Implementation

A detailed cost analysis will be generated detailing the cost of installing the Class A system on the coach. A report will be written detailing performance data and recommending potential design improvements.

8.5.20. Optimize Class A Design

Data from the cost analysis and beta tests will be used to optimize the design of the Class A multiplexing system.

8.6. Phase IV: Class C Development

It is likely that most Class C developments will take place on third party subsystems. For example, power-trains will be developed which support J1922. The interface to external equipment will likely not use J1922 but rather J1587 for diagnostics. Because of this there may be little requirement for compatibility with Class C systems on the coach.

8.6.1. Monitor On-going Developments in Class C Multiplexing

Developments in Class C multiplexing will be monitored to determine usefulness in subsystems unique to the coach and facilitate debugging of third party equipment.

8.6.2. Upgrade Diagnostic Tester to Handle J1922 Data

The diagnostic tester will also be useful in analyzing faults on the Class C buses.

8.7. Phase V: Develop Specialty Multiplexing Subsystems

8.7.1. Evaluate Most Suitable Subsystems for Conversion to Multiplexing

Various electrical and mechanical subsystems will be analyzed in terms of cost and performance to determine which are the most likely candidates for conversion to multiplexing. A cost/benefit analysis will be generated.

8.7.2. Develop Subsystems

Numerous subsystems can be designed for use with multiplexing. Examples of these projects include:

- develop passenger message centre;
- develop data logger;
- develop remote data link;
- develop driver's RAM cartridge;
- develop ultrasonic backup system;
- develop video backup display using touchscreens;
- etc.

The operation of many mechanical subsystems can be improved using multiplexing as well. Examples of these projects include:

- develop electronic air pressure regulators;
- convert vehicle levelling system to electronic control;
- convert windshield wipers to pulsed electric wipers;
- convert baggage locks to electric;
- convert radiator shutter actuators to electric;
- convert fan belt tensioners to electric;
- etc.

Performance and diagnostic capabilies can be enhanced for other subystems.

9. CONCLUSIONS

Multiplexing is attractive for the intercity bus industry both technically and economically. Savings in excess of $1,000 per vehicle are possible. Multiplexing technology has been used successfully for several years in the trucking industry to the extent that the dash display is driven by a multiplexed bus.

As well as providing a benefit of enhanced diagnostics and reduced maintenance, multiplexing can provide significant cost savings in the wiring and installation of several of the existing coach subsystems. In particular, the coach industry will benefit by the simplicity with which options and specials can be implemented on a coach using a multiplexed system. Options will become more and more specified by the coach software rather than the hardware. No longer will customized harnesses be required. Hardware will become more generic and the coach industry will benefit from the reduced variation in the number of parts and the ability to order the generic parts in high volume.

From an economic standpoint, there is money to be made in immediately implementing multiplexed systems. However, it is desirable to be compatible with industry standards as they become established and to be able to purchase off-the-shelf hardware during the development of coach multiplexing systems.

Generally, components designed for the automotive industry are not compatible with the coach electrical system and in particular will not meet the transient protection requirements. It is important that the newly designed systems for the coach be highly reliable and it must be ensured that multiplexing components meet well-defined specifications. These specifications should be developed well in advance and address both the electrical and packaging requirements. In particular, the susceptibility of the electronic equipment to arc welding and the reliability of different connection techniques should be investigated.

Development can proceed immediately with Class B systems. It may be somewhat premature to start development with Class A systems, but the technology is progressing very rapidly. Systems can be designed while maintaining close contact with the direction the industry is taking. Currently, multiplexing technology is at a threshold where design tools exist, standards are emerging and off-the shelf integrated circuits are becoming available.

It is important to allow enough time to make the proper design decisions and have the maintenance systems well thought out and set up in advance. With complicated electronic systems on the coach it will be very important to have the necessary maintenance support.

In-vehicle multiplexing technology can be designed to be generic; the same devices developed for the coach industry can be used with little or no modification in other vehicles in the trucking industry or the military.

The main hurdle to overcome in using multiplexing technology on intercity coaches will be the acceptance of electronically intensive systems on the coach by the operators and maintenance personnel. For them, the coach must be as simple as possible. In opposition to this, the requirements of the California Air Resources Board and the Canadian government to reduce pollution have made electronic control on the coach engines a necessity. The anti-lock braking and traction control systems, soon to be introduced on the coaches, also use extensive electronics. These systems use multiplexing for diagnostics and in the near future will be marketed with interactive control using multiplexing. This will ultimately force the intercity coach industry into the multiplexing arena.

10. RECOMMENDATIONS

It is recommended that development proceed with the Class B systems on the coach. Initially, detailed specifications should be generated and an overall plan for the integration of multiplexing technology into MCI coaches should be developed and endorsed by MCI management.

Multiplexing can be phased into the coaches gradually:

1) eliminate the tell/tale signals from the harness;
2) eliminate gauge signals with DDEC II and ATEC II;
3) eliminate gauge signals for non-electronic engines and transmissions;
4) eliminate engine control and starting signals;
5) eliminate the exterior lighting signals (diagnostics regarding failed lights can be provided at this time);
6) eliminate HVAC control signals and other power loads.

Effort should continually be expended to stay abreast of developments in the industry.

11. REFERENCES

1. Esmer, Gerald P., et al., Ford Motor Co., Chrysler Corp. and General Motors Corp., Recommended Practice for a Class B Automotive Network, SAE 871554.
2. van Veldhuizen, Evert D., Philips Components, In-Vehicle Communication - Standardization and Realization, SAE 890878.
3. Betts, William Robert, Salplex Ltd., Salplex Class A Multiplex System - A Practical Application, SAE 890538.
4. Thomson, Tom, National Semiconductor UK Ltd., A Progressive Approach to Reliable, Cost Effective Multiplexed Wiring Systems, SAE 890539.
5. Inoue, Teruhisa, et al., Furukawa Electric Co., Ltd. and Mazda Motor Corp., Protocol for Automotive Local Area Network (PALNET) - A Newly Developed In-Vehicle Communicaction System Based on SAE J1850, SAE 890535.
6. Gresty N., Phillips, A. R., Rists Limited, Lucas Body Systems, A Body Switching System using the SAE J1850 (Carlink) Protocol, SAE 890542.
7. Dais, Siegfried, Chapman, Michael, Rober Bosch GmbH, Impact of Bit Representation on Transport Capacity and Clock Accuracy in Serial Data Streams, SAE 890532.
8. SAE Truck and Bus Committee Adopts CAN Protocol, Microcomputer Solutions, Intel Corporation, May/June 1990.
9. Bishel, Richard A., PACCAR Technical Center, PACCAR Inc.,Truck Diagnostics: SAE J1587, Automotive Engineering, Vol. 97, No. 11, Nov. 1989, pp 27-30.
10. Optoelectronics Designer's Catalog 1988-1989, Hewlett Packard, 1987, pp. 8-2 to 8-6.
11. Valentine, Richard, Motorola Inc., Don't Underestimate Transistor-Based Lamp-Driver Design, EDN, Cahners Publishing Company, USA, Vol. 35, No. 12, June 7, 1990, pp. 119-124.

12. BIBLIOGRAPHY

82526 Controller Area Network Chip Architectural Overview, Intel Automotive Handbook, Intel Corp., 1988.

Class B Data Communications Network Interface, Recommended Practice J1850, SAE, Nov. 1988.

Electronic Data Interchange Between Microcomputer Systems in Heavy-Duty Vehicle Applications, SAE Recommended Practice J1587.

Ford Engineering Specification ES-E4LF-1314-AA, Ford Motor Co., May 1983.

Joint SAE/TMC Recommended Environmental Practices for Electronic Equipment Design (Heavy-Duty Trucks), Recommended Practice J1455, SAE, Jan. 1988.

Optoelectronics Designer's Catalog 1988-1989, Hewlett Packard, 1987, pp. 8-2 to 8-6.

Powertrain Control Interface for Electronic Controls Used in Medium and Heavy Duty Diesel On-Highway Vehicle Applications, Recommended Practice J1922, SAE, Dec. 1989.

SAE Truck and Bus Committee Adopts CAN Protocol, Microcomputer Solutions, Intel Corporation, May/June 1990.

Serial Data Communications Between Microcomputer Systems in Heavy Duty Vehicle Applications , Recommended Practice J1708, SAE, June 1987.

Betts, William Robert, Salplex Ltd., Salplex Class A Multiplex System - A Practical Application, SAE 890538.

Bickerton, Matthew, Chauhan, Ram, Lucas Automotive Ltd. Simulation for Automotive System Design, SAE 890537.

Bishel, Richard A., PACCAR Technical Center, Maximizing Utilization of the SAE J1708 Serial Data Communication Link, SAE 861069.

Bishel, Richard A., PACCAR Technical Center, PACCAR Inc.,Truck Diagnostics: SAE J1587, Automotive Engineering, Vol. 97, No. 11, Nov. 1989, pp 27-30.

Dais, Siegfried, Chapman, Michael, Rober Bosch GmbH, Impact of Bit Representation on Transport Capacity and Clock Accuracy in Serial Data Streams, SAE 890532.

Esmer, Gerald P., et al., Ford Motor Co., Chrysler Corp. and General Motors Corp., Recommended Practice for a Class B Automotive Network, SAE 871554.

Gresty N., Phillips, A. R., Rists Limited, Lucas Body Systems, A Body Switching System using the SAE J1850 (Carlink) Protocol, SAE 890542.

Harris, John D. H., General Instrument Corp., General Instrument AUTOLAN™ - A High Speed Multilexing System for Automotive Body Wiring Systems, SAE 890541.

Hillyer, Michael J., United Technologies Electric Systems, Using Motors in Automotive Mujltiplex Systems, SAE 860394.

Inoue, Teruhisa, et al., Furukawa Electric Co., Ltd. and Mazda Motor Corp., Protocol for Automotive Local Area Network (PALNET) - A Newly Developed In-Vehicle Communicaction System Based on SAE J1850, SAE 890535.

Johnson, Wayne J., Volk, Jack R., Ford Motor Co., A Proposal for a Vehicle Network Protocol Standard, SAE 860392

Katayama, Minoru, et al., Futabal Corp., Vacuum Flourescent Display for Head-Up Display, SAE 880454.

Kiencke, Uwe et al., Robert Bosch GmbH, Automotive Serial Controller Area Network, SAE 860391.

Lawrenz, Wolghard E., I+ME GmbH, In-Vehicle Networking Requires New Development Tools, SAE 890533.

Miesterfeld, Frederick O. R., Chrysler Corp., Chrysler Collision Dectection (C2D) - A Revolutionary Vehicle Network, SAE 860389.

Nagasawa, Kazumi, Uda, Makoto, Yazaki Parts Co. Ltd., A Multiplex Protocol for Medium Scale Systems, SAE 890543.

Takai, Hideo, et al., Nissan Motor Co., Ltd., Development of Diagnostic Data Link Protocol, SAE 890540.

Thomson, Tom, National Semiconductor UK Ltd., A Progressive Approach to Reliable, Cost Effective Multiplexed Wiring Systems, SAE 890539.

Valentine, Richard, Motorola Inc., Don't Underestimate Transistor-Based Lamp-Driver Design, EDN, Cahners Publishing Company, USA, Vol. 35, No. 12, June 7, 1990, pp. 119-124.

van Veldhuizen, Evert D., Philips Components, In-Vehicle Communication - Standardization and Realization, SAE 890878.

Watanabe, H., et al., Futaba Corp., High Resolution Graphic Front Luminous Vacuum Flourescent Display, SAE 880453.

Zachos, Mark P., United Technologies Corp., Software Service in Automotive Class A and B Multplex Applications, SAE 890534